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THE ARTERIES OF THE HUMAN MIDDLE EAR, WITH PARTICULAR REGARD TO THE BLOOD SUPPLY OF THE AUDITORY OSSICLES

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Previous accounts of the sources of blood to the several parts of the middle ear have been based almost entirely on specimens in which attempts, often only partially successful, had been made to fill the vessels with colored material. Exposure of the various regions of the specimens, for observation, has been by dissecting away the overlying structures; and the observations themselves have been made either by the unaided eye or by means of the very low magnifications afforded by a hand lens or a dissecting microscope.

The present study, in contrast to those by the earlier authors on the topic, is based on the procedure of following the individual blood vessels through serial sections of temporal bone, using the magnifications, as required for accurate identification, that are afforded by the various dry objectives (16 mm, 8 mm, and 4 mm) of a com-

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pound microscope. The procedure is a tedious and a time-consuming one, but it permits avoidance of certain of the sources of errors inherent in the injection methods, particularly those caused by partial or complete failure to force the colored material into portions of a vessel or vessels. The walls of a blood vessel can be identified in a histologic preparation whether or not its lumen is filled.

The chief drawback to the method used in the present study lies in the difficulty of demonstrating quickly, to another person, the evidence for the conclusions drawn. Only those persons who have the time and the patience to follow, for themselves, the numerous small blood vessels through the numerous histologic preparations, can possibly be in a position either to confirm or to deny the correctness of the conclusions reached with respect to the points on which our observations are not in agreement with those reported, or stated, by others.

Our observations have been graphically summarized in three drawings (Figs. 1, 2, and 3). In these drawings the medical illustrator has placed the vessels, against a background of readily recognizable temporal bone morphology, in accord with the three dimensional concept we formed from tracing the vessels through serial sections. This method of presentation makes the findings of the study easier to comprehend by others than would the verbal descriptions alone.

This study is an outgrowth of our efforts to determine the blood supply of regions of the malleus and the incus in which pathologic changes had been found in the sections of certain temporal bones. The thought back of the effort to trace the vessels was that perhaps local vascular lesions were in part responsible for the formation of certain of the osseous lesions.

The findings in respect to the blood supply of the ossicles led, almost perforce, because of the interconnections of the vessels of the middle ear, to a tracing in the sections of all arteries in this region. No attempt has been made to follow in detail the arteries that go to the inner ear, or to describe them.

In large part, as was to be expected, our observations are in agreement with those made by previous students of the topic. To make clear to the reader and to emphasize those items in which our observations lead to different conclusions, or in which our observations contribute items not previously recognized with respect to the blood supply of the middle ear, these items are reported first, below. Then follows an account of the blood supply of the middle ear, in which

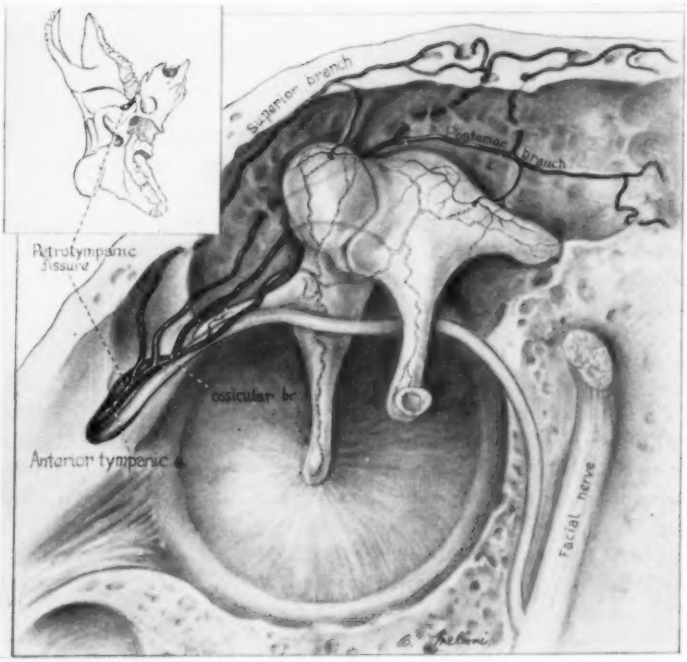

Fig. 1.—This drawing, like the two succeeding ones (Figs. 2 and 3), is based on the mental image gained by tracing blood vessels through serial histologic sections. It shows, somewhat schematically, the branching of the anterior tympanic artery and the essential relationships of the branches to other structures. Note particularly the ossicular branch, previously not recognized, which is the principal source of blood to the malleus and incus. Portrayal of the vascular convolute within each ossicle, described in the text, has not been attempted because the resultant overlapping of vessels would obscure the essential branching pattern within the ossicle; for the same reason most of the mucosal vascular networks have been omitted. The insert shows, at a much reduced scale, the location of the outer end of the petrotympanic (Glaserian) fissure, through which the anterior tympanic artery enters the middle ear.

our observations are incorporated and integrated into the observations reported previously by others.

MATERIAL AND METHOD OF STUDY

In this study, 110 series of human temporal-bone sections, from the collection of the Otological Research Laboratory of the Johns Hopkins University School of Medicine, have been examined. Ten of the series were first studied in detail, then 100 further series were rapidly searched for evidence of other vascular patterns or of major variations in the ones already identified.

The ten series of sections studied in detail are of the ears of five adult individuals, aged 20 to 43 years. Thus, both developmental and senile changes are avoided. Three of the individuals were white males, one was a white female and one a Negro female. Six of the ten temporal bones had been sectioned in the horizontal plane, and four in the so-called vertical plane; all were cut at a thickness of 24 microns.

For both temporal bones of the white female, all sections were available for examination; one had been sectioned horizontally, the other vertically. Each fifth section of two other series had been stained and mounted; for the other temporal bones only each tenth section was available. After the experience gained in tracing the vessels in the series with all sections and with each fifth section, examination of each tenth section proved to be sufficient to permit following the courses of the vessels to each region.

THE ARTERIAL SUPPLY OF THE MALLEUS AND THE INCUS

Previous to Nabeya's[1] report, in 1923, the papers about the blood supply of the middle ear contain almost nothing with reference to the auditory ossicles. This author stated that the malleus and incus are supplied by the "arteria nutricia incudo-mallei," a special branch from the middle meningeal artery which reaches the ossicles by passing along the outer wall of the "semicanalis tensor tympani," and further, that the nutrient branch to the malleus enters the neck of this ossicle and that the branch to the incus enters the bone at the base of the long crus. Nabeya's findings have not been confirmed, or denied, by other investigators.

Early in the course of our efforts to trace the vessels supplying the malleus and incus, it became apparent that in our material the major vessel to the outer ossicles is a branch of the anterior tympanic artery, not the middle meningeal, as Nabeya stated for his Japanese material, and that it enters the middle ear through or near the petro-

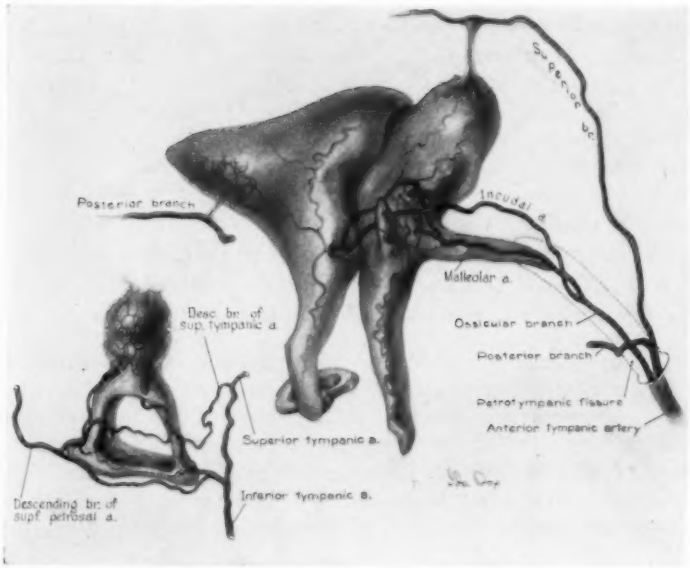

Fig. 2.—This drawing, with the malleus and incus viewed from laterally, shows the arrangement of the blood vessels to them in an ear in which the inconstant anastomosis between malleolar and incudal arteries is present, in which the malleolar artery gives a branch to the short process before entering the ossicle at the usual niche, and in which the incudal artery enters that ossicle at the least frequent location, the root of the long process. (See text matter for other possible locations of the incudal nutrient foramen and for the tributaries to the mucosal networks of the ossicles.) As in Figure 1, and for the same reason, the vascular convolute within these ossicles is not shown. The omitted portion (between the cut ends) of the posterior branch of the anterior tympanic artery passes along the lateral wall of the epitympanic recess; its location is shown in Figure 1.

The vessels supplying the stapes, shown in the insert, are described in the text matter. Its mucosal network of vessels has been omitted, except for that portion near and over the incudo-stapedial articulation.

tympanic (Glaserian) fissure, not along the tendon of the tensor tympani muscle.

For this branch of the anterior tympanic artery, which seems previously not to have been recognized, we propose the name, *Ossicular Artery*. This vessel, the major one to the outer ossicles, branches from its parent artery in the upper part of the petrotympanic fissure. It enters the middle ear either by accompanying the chorda tympani nerve through the fibrous tissue of the fissure, or by passing through a small osseous canal in one or the other of the bones that bound the fissure. The ossicular artery usually divides into two branches, one for the malleus and one for the incus, within the petrotympanic fissure or soon after entering the middle ear (Fig. 1). In two instances the division occurred near the malleus, which the ossicular artery reached by the route usual for its malleolar branch.

The branch to the malleus or the *Malleolar Artery* enters the middle ear near the anterior part of the attachment of the lateral malleolar ligament and courses in the mucosa on the upper surface of the anterior edge of the ligament. Near the attachment of this ligament to the malleus the artery enters the bone through a niche or a "nutrient foramen," at the antero-lateral aspect of the neck, or of the lower part of the head, of the malleus (Figs. 1, 2 and 4). Usually inside the niche, but occasionally just before reaching it, the malleolar artery sends a branch to the root of the short process, and may receive an anastomosis from the incudal artery. This anastomosis, which is not always present, runs in the mucosa over the joint capsule and unites the malleolar and incudal arteries before they penetrate the respective ossicles; its location is shown in Figure 2.

The course of the branch to the incus, or the *Incudal Artery*, varies more than does that of the malleolar artery. As has been stated, the ossicular artery usually gives off the incudal branch soon after, or even before it enters the middle ear. In these typical cases, the incudal artery either traverses for a short distance the lower part of the bony lateral wall of the attic or courses in the mucosa of the wall, then passes across the lateral part of the epitympanum in a mucosal fold. In this mucosal fold the incudal artery usually goes directly to the lateral part of the body of the incus, but it may go to the region of the neck of the malleus and then run in the mucosa over the joint capsule to reach the incus. In the latter cases it is slightly above the lateral malleolar ligament.

In the two instances in which the ossicular artery did not divide until near the neck of the malleus, the incudal artery passed from

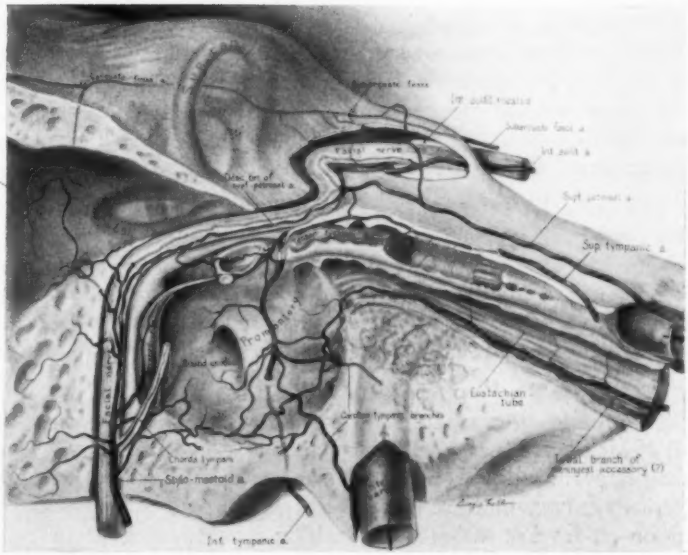

Fig. 3.—An over-all view of the locations of the arteries that supply the structures of the medial wall of the middle ear and a portion of the otic capsule. To portray the vessels of the region better, the roof of the internal auditory canal is shown as removed and the facial nerve as exposed throughout its course in the facial canal. Note particularly the anastomoses between the superficial petrosal artery and the superior tympanic, the subarcuate and the internal auditory arteries, also the anastomosis, posteriorly, between the subarcuate and the stylomastoid arteries.

its origin to the incus by running in the mucosa over the lateral part of the malleo-incudal articulation.

In contrast to the malleolar artery, which always enters the same part of the bone it supplies, the incudal artery varies considerably. It may enter the lateral (Fig. 5) or, less frequently, the medial aspect of the body of the incus in close proximity to the joint capsule, or it may enter the incus at the anterior-lateral surface of the root of the long crus (Fig. 2). Not infrequently the main stem of the incudal artery enters the bone in one of these areas and a small branch continues in the mucosa to enter the bone at one of the other two areas or at the lower end of the long crus. In those cases in which the incudal artery enters the root of the long crus or the medial aspect of the body of the incus, its course from the lateral wall of the attic

is to the region of the neck of the malleus and then across the malleo-incudal articulation. If it is to enter the root of the long crus, the incudal artery passes only across the latero-inferior portion of the joint capsule; if it is to enter the medial aspect of the body of the incus, the artery continues across the capsule, between the long crus of the incus and the manubrium of the malleus. Often, as noted above, the incudal artery receives an anastomotic branch from the malleolar artery before it enters the incus.

The malleolar artery, after reaching the marrow space of the malleus, which may even extend into the upper part of its head, forms an irregular vascular convolute, often extremely complex in arrangement, and divides into several branches. One of the branches can be traced into the short process, two or more into the bone of the head, and another can be followed down toward the tip of the manubrium.

The anterior process of the malleus (processus gracilis or processus Folii), which extends as a delicate spicule into the dense fibrous tissue of the petrotympanic fissure, receives one or two tiny branches from the ossicular artery or from its malleolar branch; the exact source depends on the level at which the branching occurs.

Inside the body of the incus, the incudal artery forms a vascular convolute (Fig. 6) similar to that in the malleus, and gives rise to branches which pass within the bone to the short and to the long process.

The mucous membrane of the outer ossicles contains a dense vascular network. Over the head and the neck of the malleus this network is supplied by small vessels that pass in mucosal folds from the tegmen tympani and from the lateral wall of the attic to the head of the malleus. These vessels arise from the superior branch and the posterior branch of the anterior tympanic artery, the same vessel that gives origin to the ossicular artery (Figs. 1 and 2). Most of the ramifications of these vessels remain in the mucosa, but a few penetrate the substance of the malleus and join the convolute inside the marrow space. Thus, to a limited degree, the mucosal vessels provide a collateral circulation for the malleus and the incus, in spite of the fact they and the ossicular artery arise from a common source, the anterior tympanic artery.

The vascular network in the mucosa over the manubrium is supplied by branches from three arteries, the anterior tympanic, the stylomastoid and the deep auricular. Only rarely does a vessel from this network penetrate the bone to unite with the branch of the malleolar artery inside the manubrium.

The mucosal network over the incus and the incudo-stapedial articulation is supplied by vessels which arise from the posterior branch of the anterior tympanic artery. Most of them pass in mucosal folds from the lateral wall of the attic to the lateral aspect of the body of the incus, but occasionally, as may be seen in Figure 5, such vessels pass from the tegmen to the superior surface of the incus. From this network a few tiny branches pass through the cortical layer of the incus and join the vascular convolute inside the marrow space. From the mucosal network over the long process of the incus vessels seldom pass into the bone.

THE ARTERIAL SUPPLY OF THE STAPES

Previous statements about blood vessels of this part of the middle ear have been mostly about the stapedial artery of embryonic life, its ontogeny and phylogeny and its occasional persistence. The reports by 14 authors previous to 1902 are well summarized in Tandler's[2] account of the embryology of the arteries of this region of the head. Instances of a persistent stapedial artery in man are reported by Hyrtl,[3, 4] Zuckerkandl,[5] Alexander,[6] Lewin,[7] Brock,[8] Adachi,[9] Altmann,[10] and by others. Adachi states that a very tiny artery which passes between the two crura and is constantly present in his material, is a remnant of the embryologic arteria stapedia. This is in accord with Zuckerkandl's earlier observations on Europeans (Austrians) but not in agreement with Broman's[11] investigations.

Nabeya[1] states that the crura of the stapes are supplied by a small branch, the "arteria stapedia," of the stylomastoid artery, that this vessel is present both in the embryo and the adult, and that it belongs to the group of structures developed from the second branchial arch. The arrangement of the branches of the "arteria stapedia" within the stapedial bone is not stated or illustrated.

In our material, blood vessels within the osseous tissue of the stapes are present only in the thickened margin of the footplate (Fig. 7) and in the neck and the head of the bone; the crura and the thin central part of the footplate seem normally to be nourished entirely by diffusion (and perhaps osmosis) from the mucosal network of vessels. That this is the case is not surprising when the thickness of a normal stapedial crus (measured from the outer to the inner face of the U-shaped section of the structure) is compared to the thickness of a Haversian lamellar system in other bones. The mucosal networks of the two surfaces of a stapedial crus seldom are separated from each other by more than three or four lamellae of osseous tissue (Fig. 8). The distance to be traversed by diffusion through the canaliculi of the bone is therefore often much less than is the case

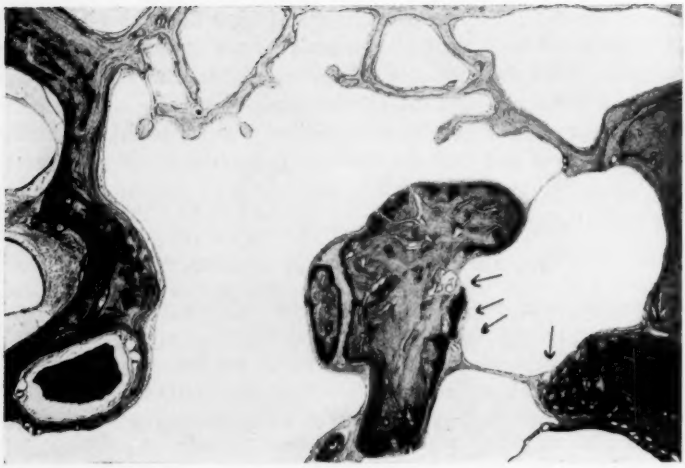

Fig. 4.—Photomicrograph of the epitympanic region of a vertical section in which the malleolar artery has been cut in five places (indicated by the arrows) along its course from the tympanic end of the petrotympanic fissure (to the right in the photograph) across the anterior part of the lateral malleolar ligament to its entrance into the malleus.

in a typical Haversian system, between the vessel in the Haversian canal and the outer lamellae of the system.

Other than in definitely pathologic specimens, blood vessels in the crura or in the central part of the footplate have been found only twice in all the material examined. The two exceptions are the stapes of a 53-year-old man in whom an arrest of development of this ossicle appears to have occurred. Each stapedial crus of this man resembles in appearance the condition normal for the embryonic stage before resorption of the bone of the primitive rod has been completed (Broman,[11] 1898, Bast and Anson,[12] 1949). A section through the anterior crus of the left stapes of this man is shown in Figure 9. It is of interest to note that in spite of the stapedial condition portrayed hearing was good, bilaterally.

The vessels within the substance of the normal stapes, in the thickened margin of the footplate and in the neck and head, are branches from the vessels of the mucosal network. The usual tributaries to the mucosal vascular network over the stapes are shown in Figures 2 and 3.

At the outset of the description, it should be noted that the vascular supply of the stapedial region, as traced in sections, differs considerably from that found by the injection technique (Nabeya,[1] Adachi[9]). For one thing, in our material two small arteries can be traced to the mucosa of the region of the anterior crus through an area in which the Japanese authors found no vessel of appreciable size; one is from the superior tympanic artery, the other branches from the inferior tympanic artery near the anastomotic junction of the parent vessels. The vessel from the superior tympanic artery either comes off well above the oval window, even near the geniculate ganglion, and descends for some distance, or in front of the oval window as a shorter branch. Both of the possible sources are shown in Figure 3, only the former is included in Figure 2. The two small arteries contribute to the vascular network around the anterior crus, and after giving off one or two tiny vessels which pass, at the base of the crus, into the thickened bone of the margin of the footplate, join each other and course along the convex aspect of the anterior crus. This vessel terminates by supplying the dense vascular network over the incudo-stapedial articulation and by a branch which enters the bone of the neck and head of the stapes. Before uniting and passing along the shaft of the anterior crus, the two vessels receive anastomoses from the vessels in the region of the posterior crus (Fig. 2).

The principal supply to the region of the posterior crus is a small artery that emerges from the facial canal above the posterior margin of the annular ligament; this vessel arises from that descending main branch of the superficial petrosal artery which courses in the facial canal between its wall and the trunk of the facial nerve (Fig. 3). (For the source and course of the parent vessel, see the account of the blood supply of the entire middle ear, p. 935 et seg.) The small artery, after emerging from the facial canal, passes in the mucosa across the annular ligament, supplies the vascular network over the posterior crus and the posterior part of the stapedial footplate, gives rise to one or two tiny branches which enter the posterior part of the thickened osseous rim of the footplate, and then passes along the convex surface of the posterior crus to contribute to the vascular network over the incudo-stapedial articulation and to send a branch into the bone of the neck and head of the stapes (Fig. 2).

The anastomotic connections between the vessels that supply the region of the anterior crus and those of the region of the posterior crus are usually three in number: (1) the tiny vessels in the bone of the rim of the footplate, from the two sources, communicate with each other; (2) a vessel of a size larger than those of the general

mucosal network courses in the mucosa of the footplate (Fig. 7) or, occasionally, in a mucosal fold from one crus to the other, as illustrated in Figure 2; and (3) a similar sized vessel, often but not always, courses in the mucosa near the inferior margin of the oval window (Fig. 2).

In perhaps a fifth of the material used in the present study a vessel could be traced from the region of the facial canal above the oval window downward to the mucosal network of the promontory. This vessel, in crossing the oval window niche, passed in some instances between the stapedial crura (i.e., through the obturator foramen) in a mucosal fold; in the other instances it passed downward in front of the anterior crus or behind the posterior crus, or by the neck of the stapes. Its course, in all the positions, was approximately perpendicular to the plane of the stapedial arch. In a few instances this vessel arises within the facial canal, directly from the descending main branch of the superficial petrosal artery that gives origin to the artery to the posterior crus of the stapes; in the other instances it appears to arise indirectly from the same source, as a branch from the mucosal network of vessels over the facial canal. Because this vessel, in any of its variant relationships, occurs in only a small proportion of the material studied, it has been omitted from the illustrations (Figs. 2 and 3) of the normal vascular pattern of the stapedial region; it may, however, eventually prove to be of interest from the standpoint of embryology.

To establish a relationship between the stapedial artery of embryonic life and any of the small arteries we have observed in the stapedial region of the adult, it would be necessary to make an intensive study of all the intermediate stages from less than 40 mm in length to the adult. Merely because an artery in the adult has a similar position with respect to the stapes that an embryonic vessel had to the developing ossicle does not warrant the conclusion that the embryonic artery persisted and directly participated in the formation of the adult artery. Most investigators of the blood vessels of the stapedial region in human embryos, in fact, reported inability to identify the remnants of the stapedial artery, near the stapes, beyond the third month. Broman's[11] observations are of particular interest on this question. He found the embryonic arteria stapedia still present, in the region of the stapes, in the 40 mm embryo. In the embryo of 55 mm this vessel could still be identified within and below the stapedial ring, but in the 90 mm embryo it had atrophied and only a strand of fibrous tissue passed through the obturator foramen. In his 180 mm stage no trace of the stapedial artery could be found in that region; only a few capillaries passed through the loose

embryonic tissue between the two crura. Tandler[2] in his report four years later came to the same conclusion as had Broman, that that portion of the stapedial artery undergoes regression in man. The only authors who conclude otherwise are Nabeya and Adachi. As mentioned above Nabeya states that the stapes is supplied by the "arteria stapedia," a small branch of the stylomastoid artery, and that this vessel is present in embryos and in adults. Adachi states that the "arteria stapedia" of the adult is a constant remnant of the embryonic vessel. Nabeya, however, does not state how many or what embryonic stages were studied, nor anything otherwise about the development of this vessel. Adachi's material consists of adults only; his statement thus appears to be based only on Nabeya's opinion.

THE BLOOD SUPPLY OF THE MIDDLE EAR

The usual treatment accorded this topic in textbooks of anatomy and otology, also in the handbooks of these specialties, is to list the names of the arteries, arranged according to parent vessels. When one attempts to learn more, by looking up the respective arteries named in the list, the statement found typically consists, for each vessel, of something like the following: "The . . . artery supplies a branch, the . . . artery, to the middle ear, which it enters through the . . . " For most of the arteries that enter the middle ear, a diligent search through the special literature, in periodicals and monographs, eventually is successful in locating a real description of the vessel in question, but an account limited to that vessel only, or perhaps to one or more closely related vessels.

A unified, inclusive, account of what is known about the blood supply of the middle ear has not been found, either in the older or in the recent literature. To try to remedy this unsatisfactory situation is the purpose of this, the second section of the present paper.

As in the first section, about the blood supply of the ossicles, the description given is based on the tracing of vessels through serial histologic sections of ears. No attempt has been made to verify, by injection or dissection techniques, the long accepted sources, external to the temporal bone, of the vessels that enter the middle ear.

The arteries which participate in the blood supply of the middle ear are: (1) the carotico-tympanic, (2) the inferior tympanic, (3) the stylomastoid, (4) the superficial petrosal, (5) the superior tympanic, (6) the subarcuate, (7) the anterior tympanic, (8) the deep auricular, and (9) the artery, whatever its origin, that courses along the eustachian tube from its nasopharyngeal end.

The arteries anastomose extensively with each other, both by continuity of their main stems and by way of the mucosal networks

Fig. 5.—Photomicrograph of the epitympanic region of a vertical section which passes through the entrance of the incudal artery into the lateral side of the body of the incus. Study of the sections anterior to the one photographed shows that in this ear the incudal artery reached the ossicle by passing directly across the lateral part of the epitympanum in a mucosal fold (for other possible routes and places of entry of the artery, see text matter). The small vessel in the mucosal fold from tegmen to incus is a tributary, from the posterior branch of the anterior tympanic artery, to the vascular network in the mucosa of the incus.

to which they contribute. It has been possible, in the sections examined, to trace each artery from its entrance into the temporal bone not only to its junction with another main stem of an artery, but also to trace each branch to its finest ramifications in the mucosa or adjacent structures (bone, muscle, nerve). Often, in tracing branches of an artery into a mucosal network of vessels, a branch of somewhat larger caliber than the others is found to be continuous with a branch, of similar caliber, that has arisen from a neighboring stem artery. The presence of such connections between stem arteries is the basis for the statements about anastomosis via the mucosal network of a specific region. If one were to include the intervascular connections potentially present by way of the smaller vessels of the mucosal networks, then each artery to the middle ear would have to be described as anastomosing with each of the others.

The first six and the last of the arteries listed above are portrayed in Figure 3; the anterior tympanic artery is shown in Figures 1 and

2. It has not been practicable to show the finer ramifications, or most of the anastomotic possibilities via the networks, in the drawings. In these drawings the region of junction between two main stems is portrayed as determined by comparing the diameters of the two vessels; it is of course the region of the smallest caliber, from which the vascular lumen increases in size in either direction. Thus, for instance, it was found that the junction between the stylomastoid and the superficial petrosal artery usually occurs in the upper third of the descending portion of the fallopian canal rather than at the level of the geniculate ganglion, which is stated in textbooks.

In some areas the vascular mucosal network is denser than in others; the denser networks are in the floor, over the promontory, and over the lower portions of the anterior and posterior walls of the tympanic cavity. The blood supply to certain regions of the middle ear appears to be mainly by way of one of these denser networks rather than from a single artery. Thus, the lower third of the inner aspect of the tympanic membrane and the corresponding segment of the inner peripheral vascular ring get their main supply from the vascular network of the floor, and the region of the round window is supplied with blood from the network over the promontory.

The *carotico-tympanic artery* (a. carotico-tympanica), usually stated to be a single vessel, often is represented, in the material examined, by two small arteries. These arteries arise as separate branches of the internal carotid artery (in its course through the vertical part of the carotid canal—a region that is included in the sections studied) and pass through separate channels in the bony partition between the carotid canal and the lower part of the anterior wall of the middle ear. If two vessels are present, one is superior to the other as they enter the middle ear, and as they course across the promontory in its mucosa to join the stem of the inferior tympanic artery in the same way as does the vessel when single. The region of the middle ear supplied from the internal carotid artery is the same whether one or two carotico-tympanic branches are present; the branches go to the anterior wall and the anterior part of the medial wall of the middle ear, from the tubal orifice to the floor.

The *inferior tympanic artery* (a. tympanica inferior), a branch of the ascending pharyngeal artery, enters the anterior part of the floor of the middle ear, accompanied by the nerve of Jacobson, by passing through the inferior tympanic canaliculus from the jugular fossa (Fig. 3). The artery then ascends over the promontory, anterior to the round window region, usually in a bony groove, but

occasionally in a bony canal. In the promontorial part of its course the vessel is joined by the carotico-tympanic artery, or arteries. Still in close relationship with the tympanic branch of the ninth nerve, it unites with the superior tympanic artery in front of the oval window or somewhat below that level. Its branches supply primarily the dense vascular networks in the floor and over the promontory; this artery also contributes to the mucosal networks around the tympanic orifice of the eustachian tube and over the lower anterior wall of the tympanic cavity, and supplies the adjacent part of the nerve of Jacobson. The main stem gives rise also to a small artery which supplies the anterior part of the stapes (Figs. 2 and 3).

The *stylomastoid artery* (a. stylomastoidea), a branch of the posterior auricular artery, enters the facial canal through the stylomastoid foramen and courses upward in the canal alongside the facial nerve to terminate by joining branches of the superficial petrosal artery. In the lower third of the vertical portion of the facial canal this vessel gives off branches posteriorly to bone and mucosa of the mastoid region, medially to the bone between the non-ampullated end of the lateral and the ampullated end of the posterior semicircular canals (sometimes these branches can be traced as far as the bone at the center of the posterior semicircular canal), and anteriorly to the mucosal vascular networks in the floor and over the lower posterior wall of the tympanic cavity. Lateral branches of the stylomastoid artery anastomose also at this level with the posterior branch of the deep auricular artery in the posterior wall and in the floor of the external auditory meatus (not shown in the drawings). Small vessels originating from the posterior meningeal artery, accompanying the nerve of Arnold, anastomose with branches from the stylomastoid artery in the region where the nerve of Arnold crosses the seventh nerve, within or near the Fallopian canal. In the lower third of the facial canal occasionally a branch of the stylomastoid artery enters the facial nerve. This vessel ascends within the trunk and may give rise to a smaller branch which descends towards the stylomastoid foramen. These branches supply the nerve fibres and soon terminate between them. One or more small branches are also given off to the chorda tympani nerve; this is the posterior tympanic artery (a. tympanica posterior) of some textbooks. It has a much smaller caliber than the other tympanic arteries and follows the chorda only to the tympanic orifice of the canaliculus chordae tympani. There it supplies mainly the posterior part of the inner peripheral vascular ring of the tympanic membrane. In a few instances a very tiny vessel accompanies the chorda further through the middle ear cavity to an anastomosis with a tiny terminal vessel from the anterior tympanic artery.

The largest branch of the stylomastoid artery is given off anteriorly at the level of the lower end of the stapedius muscle, which it supplies. In the middle third of the descending facial canal branches are also sent posteriorly and medially; some of them, within the bone of the region, unite with branches from the subarcuate artery (Fig. 3). The stem of the stylomastoid artery, whose caliber is considerably diminished beyond the origin of the branch to the stapedius muscle, then anastomoses with the descending main branch of the superficial petrosal artery, which courses in the facial canal between its wall and the trunk of the facial nerve. It may moreover anastomose with that descending branch of the superficial petrosal artery that courses peripherally within the substance of the facial nerve. This vessel usually terminates within the nerve trunk but exceptionally may continue and leave it, to join the stem of the stylomastoid artery (Fig. 3). Both anastomoses are usually near the junction of the middle and upper thirds of the vertical portion of the facial canal. At this level small arteries are also given off posteriorly and laterally to the mastoid region, to the medial half of the floor of the aditus and to the postero-superior segment of the inner peripheral tympanic vascular ring, which in this region may have anastomotic connections with the outer peripheral vascular ring. From this part of the inner vascular ring a vessel passes, in a mucosal fold near the lower border of the posterior plica of the tympanic membrane, to the medial surface of the neck of the malleus to join a vessel from the posterior branch of the anterior tympanic artery. Together they form the descending artery in the mucous membrane over the medial aspect of the handle of the malleus; the branches of this vessel, together with those from the inner peripheral vascular ring, supply the mucosal surface of the tympanic membrane.

The *superficial petrosal artery* (ramus petrosus superficialis arteriae meningeae mediae) arises from the middle meningeal artery just above the foramen spinosum and runs posteriorly and laterally, in the floor of the middle cranial fossa, with the greater superficial petrosal nerve in a groove (sulcus nervi petrosi superficialis majoris) to the hiatus of the facial canal (Fig. 3). In the sulcus several small vessels are given off to the adjacent dura and one larger vessel frequently branches off and crosses over the petrous crest, in front of the superior semicircular canal, to enter the posterior cranial fossa and anastomose with the subarcuate artery, either at the subarcuate fossa or further back in the bone. The superficial petrosal artery, in the last portion of the sulcus, sends an anastomosis to the neighboring superior tympanic artery and then divides into two main branches.

Fig. 6.—Photomicrograph, at a higher magnification, of part of the incus shown in Figure 5, to demonstrate the complexity of the arterial vascular convolute in the marrow space.

One of these branches enters the facial nerve at the geniculate ganglion and divides into two vessels, one of which travels centralward to join the facial branch of the internal auditory artery, in the fundus of the internal auditory meatus, the other of which courses peripherally as a descending branch within the trunk of the facial nerve, supplying the nerve fibres and usually terminating between them. In some instances the latter vessel may leave the trunk and anastomose with a branch of the stylomastoid artery a short distance below the level of the oval window; this variation is the one shown in Figure 3.

The other of the main branches by-passes the geniculate ganglion, not infrequently sends a short anastomotic branch to the nearby superior tympanic artery, then continues as a descending branch in the space between the trunk of the facial nerve and the bony wall of the Fallopian canal. In its course through the horizontal portion of the canal several small vessels are supplied to the otic capsule and to the bony structure and the overlying mucosa of the facial canal. This same descending branch also supplies the posterior part of the

stapes with a vessel which leaves its parent artery either in the last portion of its horizontal course or in the upper third of the vertical part of the Fallopian canal, where it terminates by anastomosing with the stem of the stylomastoid artery a short distance below the oval window (Fig. 3).

The *superior tympanic artery* (a. tympanica superior), like the superficial petrosal, arises from the middle meningeal artery just above the foramen spinosum; it runs posteriorly and laterally to pass through the canaliculus tympanicus superior, into the middle ear, with the lesser superficial petrosal nerve (Fig. 3). In the upper part of its canalicular portion the superior tympanic artery regularly gives origin to an anastomotic branch, sometimes of a relatively large caliber, to the superior branch of the anterior tympanic artery, which it reaches by passing through the petrosquamosal fissure. Near the geniculate ganglion the superior tympanic artery may anastomose, by a very short branch, with the superficial petrosal artery or with one of its descending branches. Infrequently the superior tympanic artery, from the same region, has a branch that descends inside the facial canal and that replaces or supplements the corresponding descending branch of the superficial petrosal artery. In a few instances that additional descending vessels gives origin to the artery to the posterior part of the stapes and anastomoses with the stylomastoid artery. The tensor tympani muscle, the medial half of the roof and the medial wall of the epitympanic recess are regularly supplied by branches that originate from the superior tympanic artery in its canalicular portion. The stem of the artery, still closely associated with the lesser superficial petrosal nerve and the contribution to it from the nerve of Jacobson, then descends in the promontorial sulcus to join the stem of the inferior tympanic artery in front or somewhat below the level of the oval window. Either as it emerges into the sulcus or near its termination, the artery supplies a vessel to the anterior part of the stapes (see the description of the arterial supply of the stapes, earlier in this paper).

The *subarcuate artery* (or the Artery of the Subarcuate Fossa) is not even mentioned in most textbooks and handbooks. It is the artery that courses in the elongated space, filled with fibrous tissue and vessels, that represents in the adult the subarcuate fossa of the developing temporal bone. The fact that this space under the arch of the superior semicircular canal contains an artery has long been known; and the descriptive name has been accepted by those writers who mention the vessel specifically. Agreement has not been reached, however, with respect to its origin. The answer to this question of the source of the subarcuate artery cannot be obtained from the histologic

Fig. 7.—Photomicrograph of the posterior part of a normal stapedial footplate, in a horizontal section. Note particularly (a) the absence of blood vessels in the bone of the thin part of the footplate, (b) the presence of a small artery in the bone of the thicker rim of the footplate, and (c) the artery (indicated by the arrow) in the mucosa of the footplate. The latter vessel is, for this ear, the one described in the text as the second of the anastomotic connections between the arteries that supply the anterior and the posterior parts of the stapes.

material we have examined. Other methods have therefore been used to study this problem; the findings are being recorded fully in a separate paper (Nager[13]).

For the present account of the blood supply of the middle ear, it suffices to report that the origin of the subarcuate artery was found to be variable: most commonly it arises from the internal auditory artery, but it may arise from the anterior inferior cerebellar artery or as two or more branches from one or from both of these sources. In the latter variation, the vessels join after entering the bone, to form the trunk of the subarcuate artery.

The stem of the artery, or one of its tributaries (in the cases of double or multiple origin), enters the posterior surface of the petrous portion of the temporal bone, at the subarcuate fossa. In the adult this fossa is often merely a small depression somewhat above and behind the porus of the internal auditory canal. From this entrance, which is anterior to the plane of the superior semicircular canal, the course and connections of the artery can easily be traced in the histologic sections; it passes posteriorly, laterally and slightly upwards, near the center of the bone enclosed by the arch of the canal, to the region of the antero-medial wall of the mastoid antrum, where its terminal branches are given off (Fig. 3). The other tributary (or tributaries), in those cases in which the subarcuate artery has more than one origin, usually enters the bone in the upper part of the posterior wall of the internal auditory canal and joins the other vessel soon after its entrance at the subarcuate fossa. In this same part of

its course the subarcuate artery may receive, from the superficial petrosal artery, the relatively large anastomotic branch described in the account of that vessel. Throughout its course, from subarcuate fossa to mastoid antrum, the artery has small anastomotic connections with dural branches of the posterior meningeal artery. Some of these connecting vessels pass anterior to the crus commune or the adjacent part of the superior semicircular canal, others pass posterior to these structures; frequently one of them courses near the center of the posterior semicircular canal. All of them also participate in the blood supply of the bone of the otic capsule.

The first branch of the subarcuate artery is given off soon after its entrance at the subarcuate fossa; this branch, which cannot always be identified, passes through the bone above the internal auditory canal into the so-called "petrous apex." Often the branch could not be traced to its termination because the tip region of the petrosa had not been included in the block sectioned. Several small branches arise from the subarcuate artery in its course through the arch of the superior semicircular canal; they supply the otic capsule in the region of the three semicircular canals and of the supero-posterior wall of the vestibule. From these branches, in a few instances, small vessels could be observed to pass entirely through the endosteal layer of the otic capsule of a canal; thus, the possibility exists of tiny anastomotic connections with the vessels that supply the membranous labyrinth. The terminal branches of the stem of the subarcuate artery arise in the region of the antero-medial wall of the mastoid antrum; one of them passes downward, supplies bone and mucosa of the anterior part of the mastoid region and anastomoses with branches of the stylomastoid artery (Fig. 3), the other branch passes postero-laterally to supply bone and mucosa of the supero-medial region of the mastoid antrum and the postantral cells. This branch also sends branches to the wall of the superior petrosal sinus and may anastomose with branches of the mastoid branch of the occipital artery.

A small irregular convolute of vessels is sometimes formed by the subarcuate artery in the part of its course under the superior semicircular canal; when this occurs some of the branches to the otic capsule arise from vessels of the convolute.

The *anterior tympanic artery* (a. tympanica anterior), a branch of the mandibular portion of the internal maxillary artery, is usually stated to enter the middle ear through the petrotympanic (Glaserian) fissure. Actually, the anterior tympanic artery, as traced in the histologic sections, enters the fissure and gives origin to its three major branches within the fissure; the entrance of the branches into the

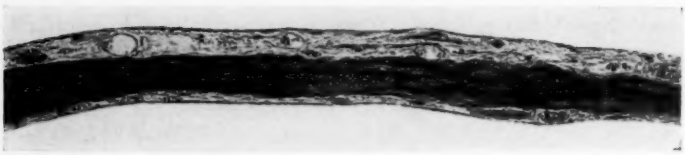

Fig. 8.—The absence of blood vessels within the bone of the crura of the normal stapes is well shown in this photomicrograph, as is also the rich vascular supply of the mucosa on both surfaces of the thin layer of bone. Mentally to orient this picture it is necessary to have in mind the characteristic "hollowed out," or U-shape, appearance of a cross section of a stapedial crus; this photograph shows only the lower arm, or flange, of the U, of a posterior crus that was longitudinally cut. The actual thickness of the bone portrayed averages about 1/20th of a millimeter. (For other points, see text matter.)

upper part of the middle ear may be through the fibrous tissue of the tympanic end of the fissure, but is usually through short canals in one or the other of the bones that bound the fissure.

The superior branch usually enters through the petrous side of the fissure, in the so-called inferior process of the tegmen. The vessel then passes upward and backward to supply branches to the bone and mucosa of the anterior and antero-lateral walls of the epitympanic recess and of the anterior third of the lateral half of the tegmen (Fig. 2). Shortly before emerging into the middle ear, the superior branch of the anterior tympanic artery is connected to the superior tympanic artery by an anastomotic vessel that passes through the petrosquamosal fissure (not shown in the drawing).

The posterior branch, after its origin from the anterior tympanic artery within the petrotympanic fissure, usually enters the bone of the tympanic side of the fissure, then courses slightly upward to enter the inferior process of the tegmen and pass backward within the bony substance of the lateral wall of the epitympanic recess. It supplies branches to the bone and mucosa of the posterior two-thirds of the lateral wall of the epitympanic recess and the lateral half of the tegmen tympani. Its terminal branches supply the lateral part of the floor, the lateral wall, and the tegmen of the aditus. After its entrance from the Glaserian fissure into the tympanic bone, one or more small vessels are supplied posteriorly to the outer peripheral vascular ring of the tympanic membrane; some of them anastomose, before reaching the vascular ring, with vessels from the anterior branch of the deep auricular artery. One or more small branches also

go directly to the inner peripheral vascular ring of the tympanic membrane, which they reach by passing medially and posteriorly through the bone. From this antero-superior segment of the inner peripheral vascular ring a vessel passes in a mucosal fold near the lower border of the anterior plica of the tympanic membrane, to the medial surface of the neck of the malleus to join a vessel from the stylomastoid artery. Together they form the descending artery in the mucous membrane over the medial aspect of the handle of the malleus; the rôle of this descending artery and its radiating branches in the nutrient supply of the mucosal surface of the tympanic membrane has already been stated in the description of the stylomastoid artery.

The superior and the posterior branches of the anterior tympanic artery, between them, also supply the mucosal vascular networks of the malleus and incus, in the manner described in the first section of this paper.

The third major branch of the anterior tympanic artery is the principal source of blood to the malleus and incus. For this branch, which seems previously not to have been recognized, the name of "ossicular artery" is proposed in the first section of this paper, to which reference may be made for the detailed description of this vessel and its branches.

The *deep auricular artery* (a. auricularis profunda), a branch from the mandibular portion of the internal maxillary artery, enters the temporal bone at the inferior aspect of the osseous portion of the external auditory canal. In the bony floor of the canal it usually divides into two major branches, an anterior and a posterior, and several smaller ramifications. The posterior branch largely supplies the bony structures and the overlying integument of the posterior half of the canal wall, anastomoses medially and posteriorly with branches from the stylomastoid artery and supplies vessels to the postero-inferior segment of the outer peripheral vascular ring of the tympanic membrane. It then ascends superficial to, or sometimes within, the posterior bony canal wall to the postero-superior segment of the outer vascular ring and at this higher level frequently anastomoses again with branches from the stylomastoid artery. The posterior branch then approaches the tympanic membrane and descends between the epidermis and the layer of radial fibres, passing at first behind the manubrium and then superficial to it, in its lower half. Branches from this descending vessel follow the direction of the radial fibres to the periphery. In some instances the artery divides near the distal end of the manubrium into two branches which form an elliptical loop around the umbo and send vessels radially to

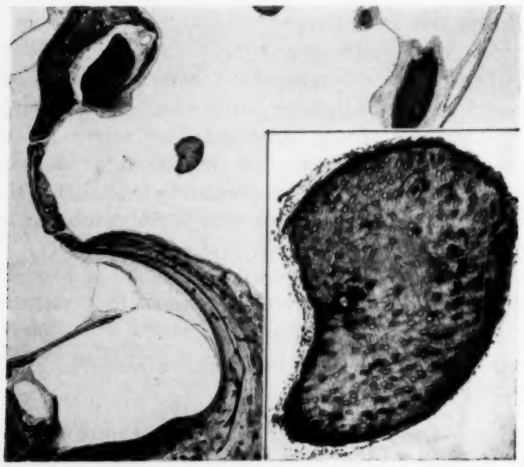

Fig. 9.—See text matter for explanation of this abnormal stapes, in which blood vessels are present in the crura and in the bone of the central part of the footplate. The higher power picture (insert) of this abnormal crus is at the same magnification as is the part of a normal crus shown in Figure 8.

the inferior part of the pars tensa. In other instances the same artery simply ramifies radially at the umbo.

The anterior branch of the deep auricular artery supplies the bone and overlying integument of the anterior half of the external auditory canal wall and sends vessels to the antero-inferior segment of the outer peripheral vascular ring. It also, by branches that pass through the bone beneath the tympanic sulcus, contributes to the mucosal vascular network of the floor of the middle ear, and by this route may anastomose with the other vessels that contribute to this network. The stem of the anterior branch ascends in the anterior canal wall, where it gives a few small branches that anastomose in the bone with ones from the posterior branch of the anterior tympanic artery, and terminates by entering the antero-superior segment of the outer peripheral vascular ring of the tympanic membrane.

The artery, whatever its origin, that courses in the wall of the eustachian tube not only supplies the walls of the tympanic part of the tube but also participates in the blood supply of the middle ear.

It sends branches to the mucosal networks of the anterior wall and of the promontory, and anastomoses with the carotico-tympanic artery. In the drawing (Fig. 3) this artery is labelled, with a question mark, as being from the meningeal accessory, because this appears to have been its origin in the only case in which it could be traced, in the histologic sections, to a source that can be identified with reasonable certainly. In this specimen, the origin is from a small artery that runs near the middle meningeal artery beneath the foramen spinosum; the internal maxillary artery, however, was not included in the block of tissue sectioned. The artery along the upper part of the tube may, of course, arise from any of the several arteries that are known to send branches to the nasopharyngeal end of the eustachian tube, or from the anastomotic network there formed by these branches.

The blood supply of the posterior part of the mastoid region could not be determined from the histologic material examined, because usually this part of the temporal bone had not been included in the blocks of tissue sectioned. The observations made on this point give no reason to doubt the customary statement in textbooks that the mastoid branch of the occipital artery supplies this part of the middle ear.

COMMENT

The procedure used in the present study, in which the vessels and their branches have been traced through serial histologic sections, reveals that anastomotic connections between the arteries to the middle ear are even more plentiful than was indicated by the studies of them with injection and dissection techniques. The procedure used also demonstrates the sources of blood to the ossicles, with a clarity not possible by the methods in which the ossicles are removed, or otherwise disturbed, in order to make the observations. It is surprising, however, that in spite of the difficulties inherent in the techniques they used, previous investigators of the subject did not discover the artery that is the principal source of blood for the malleus and the incus nor the avascular nature of the crura of the stapes.

In most previous studies attention was directed mostly, or exclusively, to the blood supply of the tympanic membrane. For this part of the middle ear, as was to be expected, tracing of the vessels through histologic sections has confirmed the findings earlier workers reported but has not added much. A drawing to show the tributaries to the inner and the outer vascular rings of the tympanic membrane has therefore not been attempted; in our descriptive text the emphasis has been placed on where the respective tributaries enter the vascular rings. Good descriptions and illustrations of these vascular networks

of the tympanic ring can be found in the papers by Prussack[14] (1868), Popper[15] (1869), Burnett[16] (1876), Moos[17] (1877), and Gerlach[18] (1885).

SUMMARY

By tracing blood vessels, with a microscope, through serial histologic sections, more information has been obtained about the arteries to the middle ear than was possible with the injection techniques used by previous investigators of this subject. For each of the arteries a detailed description is given of its course, anastomoses and branches. On many items, as was to be expected, the information obtained by the method of study used merely adds details to previous accounts. With respect to the blood supply of the ossicles, however, several entirely new facts were revealed; the arteries to the ossicles are therefore described in a separate section of the paper, with drawings and photomicrographs.

A previously unrecognized branch of the anterior tympanic artery, for which the name of "ossicular artery" is proposed, was found to be the principal supply for the malleus and the incus; the mucosal networks of these ossicles provide only a secondary supply. The stapes receives blood from three arteries; the superficial petrosal, the superior and the inferior tympanic. None of the arteries in the stapedial region can be definitely identified with the stapedial artery of embryonic life. No vessels of any kind enter the thin parts of the stapes, the central region of the footplate and the shafts of the crura.

We desire here to express our gratitude to Dr. Stacy R. Guild for guidance and help both during the study of the material and during the preparation of this report of the observations.

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LXXXIV

STUDIES ON THE OTIC LABYRINTH

VI. ANATOMIC EXPLANATION FOR THE HEARING DIP AT 4096 CHARACTERISTIC OF ACOUSTIC TRAUMA AND PRESBYCUSIS

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Why does nerve deafness first make itself manifest in the range around 4000 to 6000 cps and why does acoustic trauma show the greatest damage in this same region? Many have pondered this question.

It makes no difference what frequency of sound it is that causes acoustic trauma, the first and greatest damage is here. Traumatizing tones of 1000 or 2000 by-pass the localization of 8000, do damage at 6000 to 4000 and then pass on to their own respective locations. Rüedi and Furrer[7] offer an explanation based upon the eddies described by Békésy.[1] They state that the eddies change direction at about this point and would depress and put tension on the basilar membrane here. There are other explanations offered, one of which is based upon the proximity of the first half of the basal turn to the middle ear and another upon the entrance of the cochlear branch of the internal auditory artery and the division of that artery which takes place near the upper part of the first half of the basal turn.

With the 4000 to 6000 dip in mind, I dissected the basal turn of five cochleas (specimens No. 3, 4, 5, 41 and 118) and inspected them for some other possible anatomic explanation. According to the work of Crowe, Guild and Polvogt,[2] 4096 is located about 7 to 10 mm away from the basal end of the cochlea and 6000 at six or seven mm. Wheeler[8] claims that the greatest damage from acoustic trauma occurs at 6000, not 4000. If one views the cochlea from above, i.e. from the apex, the curve in the beginning of the basal turn is so slight that it is possible to draw a straight line from the vestibule to a point 6 or 8 mm into the cochlea before it strikes the outer wall of the cochlear canal (Fig. 1). When viewed from the side, i.e from the middle ear, it is found that the basal turn of the coil lies at a somewhat higher level than the vestibule. The vestibule

From the Department of Otolaryngology, University of Minnesota. Work done in part in the Department of Otolaryngology, Columbia University.

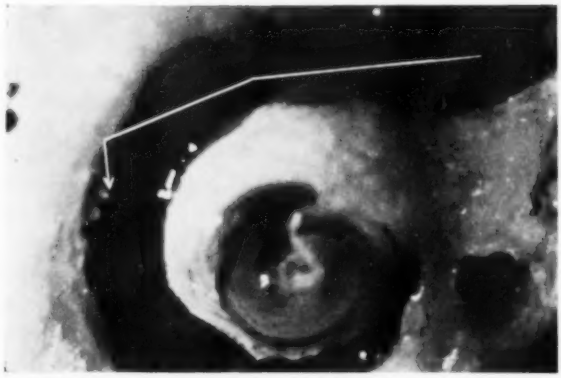

Fig. 1.—Photograph of basal turn of Specimen 5 dissected in such a way as to show the entrance to the basal turn from the vestibulum. As can be seen, a straight line could be drawn from the vestibulum for about 6 mm before it would strike the outer wall. If a force should follow this straight line, it would be reflected from the roof and outer wall onto the basilar membrane and organ of Corti about as indicated. As a matter of fact the lines of force would tend rather to bend and strike somewhat deeper.

as it merges into the cochlea forms a funnel, which is directed somewhat upward with reference to the cochlear canal (Fig. 1 and 2). A line drawn in the axis of this funnel would strike the roof of the canal at an acute angle some three or four mm from the beginning of the turn (Fig. 3) and, if reflected at the same angle, would strike the outer wall some 6 or 8 mm from the beginning of the turn (Fig. 4).

If there were a continuous flow through the cochlea from the vestibule, then a jet would be formed approximately along the lines indicated, which would make an impact against the outer wall at six or eight mm from the beginning of the turn. There would be a change of direction here with a centripetal acceleration directed toward the center of rotation. There would also be a centrifugal force of corresponding magnitude directed against the wall at the point of impact.* From the point of impact on the outer wall the force

*The centripetal acceleration could be calculated from the formula $a=\frac{V^2}{r}$ (where "a" designates centripetal acceleration and V and r, velocity and radius of rotation respectively). The centrifugal force necessary to produce the centripetal acceleration would be expressed by the formula $f=m\frac{V^2}{r}$ (f and m designating force and mass respectively).

would be deflected toward the apex and downward against the basilar membrane and the organ of Corti (Fig. 1).

The flow during sound vibration is, of course, not continuous. It is rather the oscillating movement of a compression wave.[3] The same principles, however, would apply but the magnitudes of the forces involved would be much smaller.[5] There would be an area of greater pressure at the point of impact at six or eight mm on the outer wall than on the inner wall at that level or the outer wall at four or five mm (location of 8000 cps which is often preserved in early presbycusis and in less severe acoustic trauma). At low intensities near threshold, or ordinary conversation, these differences in pressure would be infinitesimal and negligible, but at high intensities of sound pressure they could be significant.†‡

Crowe, Guild and Polvogt[2] found that the earliest pathologic change in their "abrupt hightone loss" group consisted in atrophy and degeneration of the external sulcus cells. They stated that there was no apparent etiologic explanation for this fact. If it is a fact

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†Dr. Edward L. Hill of the Department of Physics of the University of Minnesota has worked out the following formula:

If a sound wave goes through a tube of water and is reflected straight back from a closed end (this makes a 180° turn) the pressure upon the closed end is twice the mean pressure of the wave.

$W = D \cdot C \cdot A^2 \cdot F^2 \cdot K$ (constant)

$$W = \frac{\overline{P^2}}{D\ C^2}$$

$$\overline{P} \sqrt{W\ D\ C^2}$$

The pressure upon the wall at a turn of less than 180° would be between that in the wave and twice that in the wave.

In the cochlea, such differences in pressure would be small for ordinary sound.

($\overline{P}$=average pressure; W= energy flux=energy per sq cm per second on sound wave front and on rigid walls; D=density of fluid; A=amplitude of particle motion; C=velocity of sound; F=frequency.)

‡To further elaborate, the greater the flow in the oscillating to-and-fro movements of the perilymph, the greater would be the pressure difference between the inner and outer walls. At low intensities, the flow movement of the perilymph is so infinitesimal that, in the words of Dr. Hill, "the molecules wouldn't know there is a turn there." If one could imagine an impulse passing through the perilymph without any flow, the pressure would be transmitted equally in all directions and there would be no difference in the pressure between the inner and outer walls. At high sound intensities, the to-and-fro movement can be of comparatively considerable magnitude, so much that differences in pressure at this point of change of direction could be significant.

Fig. 2.—Photograph of basal turn in specimen 4, as seen from the side. V—vestibulum. S.V.—scala vestibuli. ST—scala tympani. It can be seen that the axis of the passage from the vestibulum to the scala vestibuli rises for the first 2 or 3 mm and that the axis of the canal falls somewhat beyond 4 or 5 mm. From the appearance, one would expect a point of increased impact about where the letters SV are placed. This is about the location of the frequency 6000.

that there is a point of greatest impact against the outer wall of the cochlear canal somewhere between six and eight mm from the base, then, because of the conformation of the cochlear canal, the impulses from this impact as they strike against the outer wall of the cochlear canal would be deflected or bent downward along the upper arm of the spiral ligament to strike the floor of the outer sulcus and the organ of Corti. This could cause overextension of the insertion at the outer margin of the tectorial membrane, with stretching or tearing of this sheet or membrane of insertion. In some of the specimens reported in Study I,[4] the impression was received that the sheet or membrane of insertion extended all the way across the outer sulcus. Be that as it may, it was observed in some specimens that it was possible to tear this complex sheet of insertion in such a way that the contents of Hensen's cells ballooned out and became extruded. In their article, Crowe and his co-workers do not discuss the cells of Hensen specifically, mentioning only the cells of the outer sulcus but, in the photomicrographs reproduced in their article, it appears that the changes in the external sulcus cells are paralleled by similar changes in Hensen's cells. Might it not be that the changes in both of these cell masses are due to damage to the sheet of insertion of the outer border

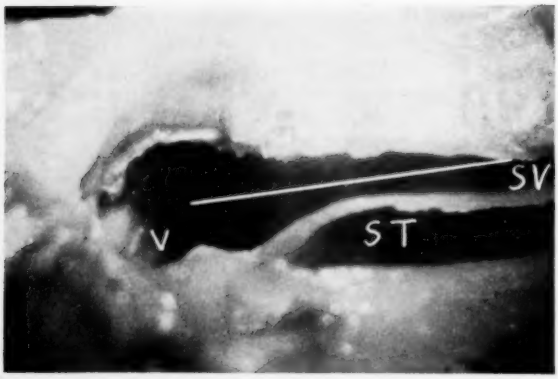

Fig. 3.—A view of specimen 3 illustrating the funnel-like form of the entrance into the scala vestibuli.

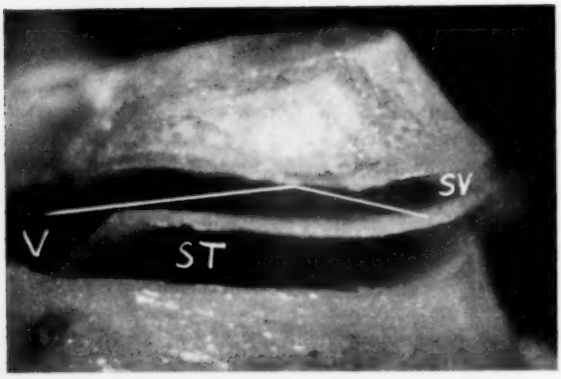

Fig. 4.—Basal turn of specimen 3, dissected to show the conformation of the beginning of this turn. The lines indicate the direction of thrust from a force traveling in straight lines. Undoubtedly the lines of force actually bend but the general direction and points of increased pressure would be about as indicated.

of the tectorial membrane with resulting injury to the cells to which this membrane is attached?

In the 79 specimens which Crowe, Guild and Polvogt studied, they failed to find any lesions in one-fourth of them, either in the middle or inner ear, to account for the hearing loss. If the hearing loss were due to injury to the sheet of insertion along the margin of the tectorial membrane, it is quite conceivable that this might have been the pathologic change which they failed to see. Since the insertions of the tectorial membrane are invariably destroyed in histologic preparation, they would inevitably fail to find such premortem lesions.

If this concept is correct, it would explain the fact that hearing loss both from presbycusis and acoustic trauma is greatest at 4000 to 6000 cps. The force of impact in this area applied a thousand times a second over a period of decades, although only slightly greater than elsewhere in the cochlea, might serve to stretch and wear the marginal insertion most at this spot. Severe impulses (or shock waves), such as from blasts or extremely loud noise, occurring more occasionally, might serve to cause this same type of damage, as might the sound found in certain noisy occupations. The stapedius and tensor tympani muscles contract with noise in such a way as to protect the cochlea from excessive amplitudes. However, the reflex time for these muscles to act is about ten milliseconds.[6] Many a powerful thrust could enter the cochlea in these ten milliseconds and cause damage at the point of impact described. This would emphasize the importance of protection from excessive sound, not only in those already showing nerve deafness, but in everyone throughout life.

SUMMARY

A possible explanation for the localization of nerve deafness from acoustic trauma and presbycusis is offered in the conformation of the entrance into the cochlear canal from the vestibule and the anatomical characteristics of the first half of the basal turn. From these anatomical facts, it would seem that there is a point of greatest impact upon the structures in the cochlear canal some six or eight mm from the beginning of the basal turn.

626 MEDICAL ARTS BLDG.

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LXXXV

ABSORPTION FROM THE NASAL MUCOUS MEMBRANE

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There are many conditions requiring systemic medication in which parenteral injection may be either undesirable or impractical, as, for example, when medication must be given by untrained personnel or must be self-administered. Further, oral medication may not be indicated either because the patient is nauseated or vomiting, or because of a slow rate and inadequate degree of absorption.

Recent laboratory studies[6] have demonstrated the importance of the nasal mucous membrane as a route for drug administration when systemic effects are sought. Hyoscine has been shown to be absorbed at a rate and to a degree more nearly resembling subcutaneous than oral administration. This would appear to refute the findings of some earlier workers who either found no apparent systemic effects following intranasal medication, or else attributed these effects to the swallowing of excess medication which had spilled over into the throat. Clinical observations which tend to confirm the importance of the systemic effects of drugs administered intranasally have recently been described by Gay and Polvogt.[3]

Considerable interest has been aroused in recent years in the toxicity of organic phosphoryl compounds because of certain hazards involved in their use as insecticides. In addition, much work has been done in searching for antidotes because of the potential use of these compounds in chemical warfare. It is widely recognized that atropine is an effective antidote in cases of poisoning by these compounds.[1, 7] Because of the success of the earlier studies with hyoscine, which bears a close pharmacological resemblance to atropine, and because of the important potential uses of atropine, it was considered worth-while evaluating the intranasal route for the administration of atropine.

PART I—FURTHER STUDIES ON SYSTEMIC MEDICATION WITH HYOSCINE

To make the study more complete it seemed desirable to pursue the hyoscine experiments a bit further than the original work.[6] Oral capsules, intranasal drops and spray, and subcutaneous injection had already been compared; sublingual tablets were now evaluated as regards the rapidity and degree of absorption. The effect of the addition of a detergent to nose drops had also been determined; in view of its effectiveness in increasing the rapidity of absorption of nasal sprays, it was decided to study in addition the effect of hyaluronidase, the spreading factor of Duran-Reynals,[2] on intranasal medication. Finally, since the character of the nasal mucosa varies considerably throughout the nose, it appeared of interest to compare the rate and extent of absorption from various parts of the nose. Because the basis on which to continue had already been established with hyoscine, the present experiment was set up along the same general lines.

EXPERIMENTAL PROCEDURE

Because the degree of pupillary dilatation and of cycloplegia induced had been found to be unsatisfactory, the criterion for determining the systemic effect of hyoscine was the decrease in salivary flow following medication. The subjects, all healthy young Air Force recruits, were given fresh sticks of chewing gum for each test period and instructed to collect in bottles of known weight all saliva produced during a five-minute period. Two control periods fifteen minutes apart were used, medication was then applied, and further saliva collections were taken after intervals of 15, 30, 60, 90, and 120 minutes. The weights of saliva were determined and converted to percentages (a method previously found to render significant results). The value for the second control period was considered as the reference level, that is, 100 per cent. This was done to eliminate the effect of a learning factor which was present in the majority of cases and which would have tended to mask the results slightly if the first control period had been used as the reference level.

To facilitate comparison, for each different test condition a total of ten subjects ($n=10$) was used. Unless otherwise stated, all changes in saliva production have probability values of 0.05 or better.

To avoid repetition of work that had already been done, the values for a control group (oral placebo), for those receiving oral capsules of hyoscine, and for those receiving subcutaneous injection were taken from the earlier study. However, the figures were altered slightly, but not significantly, in that the second control period rather

than the first was now used as 100 per cent. The total dose of hyoscine was 0.65 mg in each case except for one group of subjects, specifically indicated, where the dose was 0.60 mg.

It had been shown that the addition of a detergent to a nasal spray increased the rate and degree of absorption, and also greatly decreased the variance in a group of ten subjects.[6] In the present experiment, 0.6 mg of hyoscine was mixed in a solution of hyaluronidase in the strength of 1.0 unit to 0.4 cc, and administred as nose drops to determine what effect, if any, the "spreading factor" might have on absorption through the nasal mucosa. The total volume, 0.4 cc, was chosen because it had been determined earlier that 0.2 cc of solution was about the maximum volume that could be instilled into one nostril without overflow into the nasopharynx.

In the next series of experiments, nose drops were administered with the subjects' heads in different positions so as to direct the medication to different portions of the nose. In each case medication consisted of 0.65 mg of hyoscine in a total volume of 0.4 cc of normal saline. It seemed of interest to determine whether or not there might be any difference in the rate and degree of absorption from the thin mucous membrane over the nasal septum as compared to the richly vascular tissue of the inferior turbinate. Because of the narrowness of the normal nose, and to avoid contact of the nose drops with both the nasal septum and the inferior turbinate at the same time, a small celluloid partition was placed gently in the subject's nose prior to medication, and the hyoscine drops (in this case, a dose of 0.65 mg in a total volume of 0.2 cc of saline) administered under direct vision to the appropriate side of the partition. Since conditions were the same for both groups, it was felt that any possible effect that irritation of a foreign body might have on saliva production would be equal for both groups. In actual practice, there was only one subject who complained about the foreign body and who was seized with a fit of sneezing; since questioning revealed that he was suffering from acute seasonal allergic rhinitis, he was not allowed to continue as a test subject.

Finally, nose drops were instilled along the floor of the nose in one group of subjects, and into the upper half of the nose in another group who held their heads in the "Proetz position" during and for several minutes following medication.[4] To complete the study, a solution of hyoscine in Duponol (a detergent) was sprayed into the nasopharynx of a final group of subjects.

During the course of these experiments, it was observed that there was considerable variation in the actual dose administered when

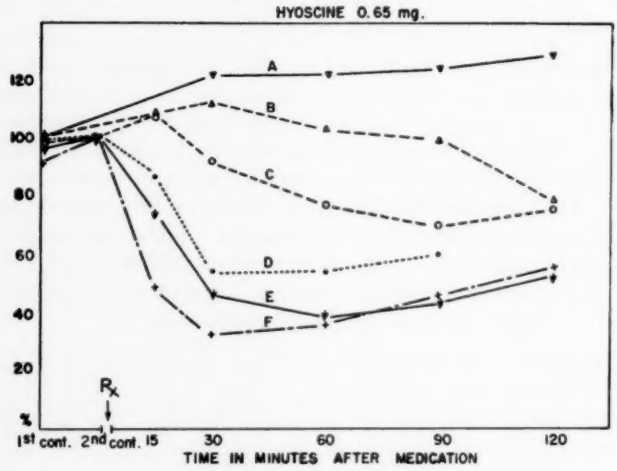

Fig. 1.—Change in saliva production with time expressed as per cent of second control specimen. Curve A, oral placebo. Curve B, oral capsule of hyoscine. Curve C, sublingual hyoscine tablets. Curve, D, hyoscine (0.60 mg) with hyaluronidase (1 unit in 0.4 cc). Curve E, hyoscine nose drops (floor of nose). Curve F, subcutaneous hyoscine.

the spray bottles were used rather than nose drops. This was felt to be largely a factor of wear and tear on the nozzle of the spray bottle and the lack of uniformity was so marked that the majority of the present series of experiments was carried out with nose drops to insure better control of the dose administered. In the one group of subjects in whom the hyoscine-detergent solution was sprayed into the nasopharynx, a special experimental spray bottle was constructed to insure delivery of a uniform quantity of solution.

RESULTS AND DISCUSSION

The absorption of hyoscine intranasally has already been shown to occupy a position intermediate between oral and subcutaneous administration as regards the rate and degree of antisialogigic action.[6] Sublingual administration was now proven to be definitely inferior to both the intranasal and subcutaneous routes, as shown in Figure 1. Sublingual tablets tended to be absorbed somewhat more rapidly and completely than did oral capsules, but it should be emphasized that this was only a trend ($P=0.1$). Sublingual fluid was not evaluated.

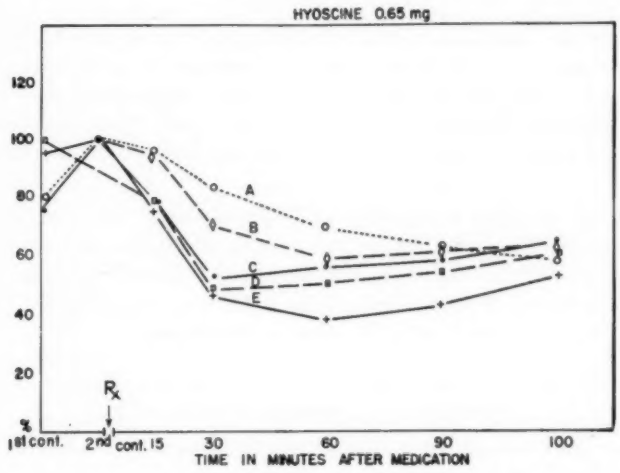

Fig. 2.—Comparison of hyoscine absorption from different areas of the nose. Curve A, nasopharynx (hyoscine spray in detergent). Curve B, nasal septum. Curve C, inferior turbinate. Curve D, roof of nose (Proetz position). Curve E, floor of nose.

Hyaluronidase was added to the hyoscine nose drops given one group of subjects, and was found to have no significant effect either in speeding up the initial absorption or in the degree of absorption attained during a 90-minute period of observation.

Hyoscine nose drops were next administered with the head in different positions in order to evaluate differences in the rate and degree of absorption through different parts of the nasal mucous membrane. The results are depicted graphically in Figure 2. The most noteworthy finding was that at both the 15- and the 30-minute periods following medication, there was significantly less absorption through the nasal septal mucosa than through the mucous membrane of the floor of the nose, of the inferior turbinate, and of the upper portion of the nose.

The same was also true for absorption from the nasopharynx; here, too, the thin mucous membrane did not absorb the hyoscine preparation either as rapidly or as completely as did the more vascular mucosa of the inferior turbinates and other portions of the nose. This latter comparison is valid even though in this experiment a spray was used rather than nose drops, since it had been shown earlier that the

addition of a wetting agent to a nasal spray provided as effective a medium of drug administration as nose drops.

After the 30-minute period the difference in the degree of absorption from the nasal septum and the nasopharynx as compared to other areas of the nose was no longer of statistical significance. This may be partially because the drug effect may tend to wear off somewhat more rapidly from an area in which absorption is initially more rapid.

Perhaps the most practical clinical application of this latter series of experiments is the fact that there was no significant difference in the systemic effect of hyoscine nose drops regardless of whether they were administered to the roof of the nose (Proetz position), the floor of the nose, or directly onto the inferior turbinate.

PART II—SYSTEMIC EFFECTS OF ATROPINE FOLLOWING INTRANASAL ADMINISTRATION

The justification for a study of the intranasal route for the administration of atropine has already been discussed. Its pharmacologic resemblance to hyoscine would facilitate a ready comparison of the two drugs, particularly since the criterion for evaluation of systemic effect could continue to be the depression of salivary flow following medication.

EXPERIMENTAL PROCEDURE

The procedure for the atropine experiments was essentially the same as has already been described. Again, for most of the test procedures, ten subjects were used, and all changes in salivary production have probability values of 0.05 or better unless otherwise indicated.

In order to determine an effective dose of atropine nose drops, doses of 0.3 and 0.65 mgs, respectively, were given to two groups of five subjects on the first day. Because the response was considered so slight in comparison to previous studies with hyoscine, the next three groups of ten subjects were administered successively doses of 1.0, 1.5, and 2.0 mg of atropine in normal saline. The results, shown in Figure 3, will be discussed later.

It was next desired to compare the effect of various routes of administration, as had been done earlier with hyoscine. Doses of 1.5 mg were administered as nose drops in saline and as a spray in Duponol, 1.6 mg was administered in the form of sublingual tablets, and 1.0 mg was injected subcutaneously.

To evaluate the effect of a detergent and also of hyaluronidase on the absorption of nose drops, a dose of 1.5 mg of atropine

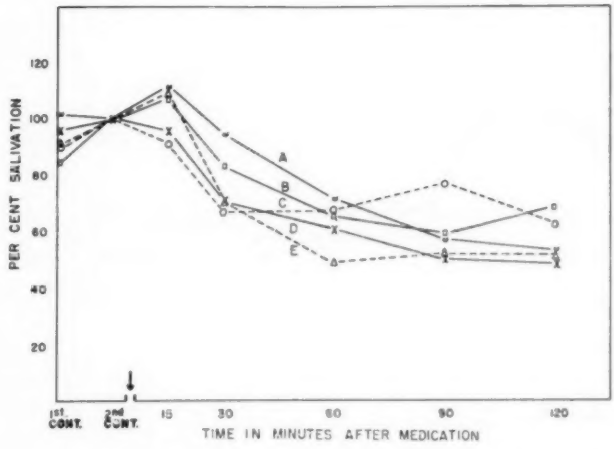

Fig. 3.—Atropine nose drops. Change in saliva production with time expressed as per cent of second control specimen. Curve A, 0.3 mg (n=5). Curve B, 1.0 mg (n=10). Curve C, 0.65 mg (n=5). Curve D, 1.5 mg in Duponol (n=10). Curve E, 2.0 mg (n=10).

was administered in normal saline, in 0.01 per cent Duponol, and in a solution of hyaluronidase containing 1.0 unit in 0.4 cc to three groups of ten subjects.

Finally, since the basis for these experiments had already been formed with the hyoscine studies, a direct comparison was made of the effect of hyoscine, 0.65 mg, administered subcutaneously and as nose drops, and of atropine, 1.0 mg injected subcutaneously and 2.2 mg given as nose drops. Because a very few subjects did have mild reactions to the larger doses of atropine, it was felt neither necessary nor advisable to inject more than 1.0 mg of atropine subcutaneously.

RESULTS AND DISCUSSION

Trial doses of 0.3 and of 0.65 mg of atropine were given intranasally to two groups of five subjects to estimate the effect on saliva production. The comparison between equivalent doses of hyoscine and of atropine will be discussed later, but it may be stated here that the response was not very great (Fig. 3). Accordingly, 1.0, 1.5, and 2.0 mg of atropine were administered as nose drops to successive groups of ten subjects. The response was somewhat more gratifying, as indicated in Figure 3, but even so the only statistically significant

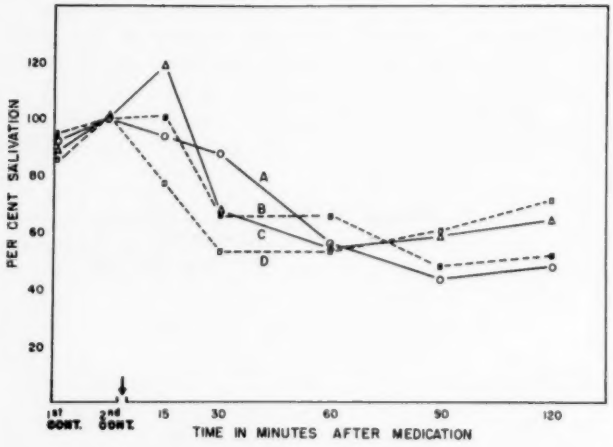

Fig. 4.—Different routes of atropine administration; (n=10). Curve A, sublingual tablets, 1.6 mg. Curve B, nose drops, 1.5 mg. Curve C, spray (in Duponol), 1.5 mg. Curve D, subcutaneous injection, 1.0 mg.

difference (P=0.05) between the 1.0 mg dose and the 2.0 mg dose was at the 60- and the 120-minute period following medication. The 1.5 mg dose was not significantly more effective than the 1.0 mg dose, nor was it significantly less effective than the 2.0 mg dose.

A comparison of the effectiveness of different routes of administration of atropine was made next, and the results are indicated in Figure 4. Atropine nose drops, 1.5 mg, had about the same effect as an atropine spray (in a detergent) of the same dose. This was in agreement with the hyoscine experiments. Sublingual tablets were significantly less effective at the 30-minute period than either the spray or the nose drops, but after that the curves ran together, as seen in Figure 4. A smaller dose, 1.0 mg was injected subcutaneously, and at the 15-minute period was definitely more effective than doses of 1.5 mg administered sublingually as well as intranasally. It was still significantly superior to the sublingual route at 30 minutes, and there was a trend for it to be more effective than the nose drops at 30 and at 60 minutes (P=0.09).

The effect of a detergent and also of hyaluronidase added to the atropine nose drops was determined using doses of 1.5 mg of atropine. At no point during the two hours of observation was there any significant improvement in absorption with either the de-

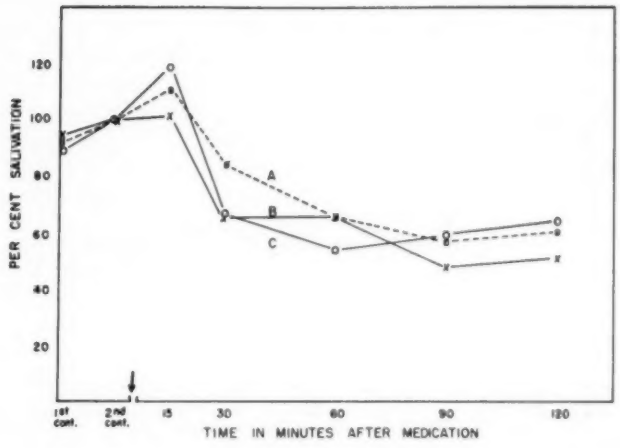

Fig. 5.—Atropine nose drops, 1.5 mg. Curve A, atropine in hyaluronidase. Curve B, atropine in normal saline. Curve C, atropine in Duponol.

tergent or the hyaluronidase (Fig. 5). It had been shown earlier with hyoscine that the addition of Duponol to a nasal spray produced a rate and degree of absorption approaching that obtained with nose drops, but when the detergent was added to nose drops, there was no further improvement.

In view of the successful results that had been obtained with hyoscine, it was of considerable interest to compare the absorption of intranasal hyoscine to intranasal atropine. It can be seen in Figure 6 that 0.65 mg of hyoscine injected subcutaneously produced a more rapid and a greater degree of salivary depression than did 1.0 mg of atropine; the probability value is 0.05 or better for the 15-, 30-, and 60-minute periods. When intranasal administration was compared, it was noted that 0.65 mg of hyoscine produced a systemic effect similar to that resulting from application of 2.0 mg of atropine. At the 15-minute period, the hyoscine was actually more effective than the atropine ($P=0.01$) and this difference was still evident as a trend ($P=0.06$) at 30 minutes. The fact that it required three times the dose, by weight, of atropine nose drops to produce the same degree of salivary depression as 0.65 mg of hyoscine was of interest, particularly since this larger dose (2.0 mg) of atropine did result in a few cases of mild atropine toxicity.

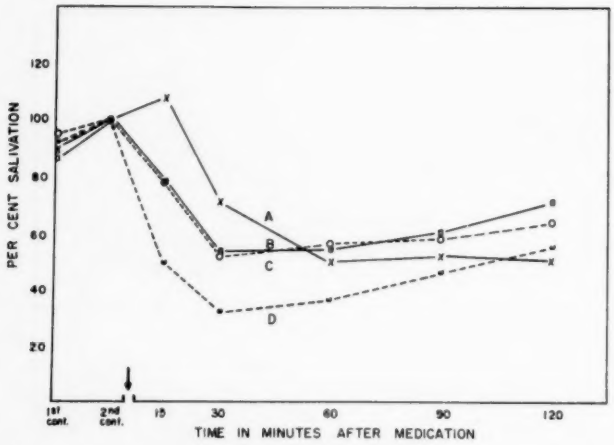

Fig. 6.—Comparison of atropine and hyoscine. Curve A, atropine nose drops, 2.0 mg. Curve B, subcutaneous atropine, 1.0 mg. Curve C, hyoscine nose drops, 0.65 mg. Curve D, subcutaneous hyoscine, 0.65 mg.

On the subject of toxicity, it is worth recording that one group of airmen were sprayed with 1.5 mg of atropine in Duponol in one experiment; one subject suffered a moderately severe toxic reaction (pupillary dilatation, mild nausea, dizziness, and disorientation) which, fortunately, had completely cleared up by the next morning. In checking back on the weights of the spray bottles, it was discovered that he had accidently been given slightly more than 3.0 mg of atropine. As a result of this particular incident it was decided to abandon the use of the spray bottles until a special unit could be designed which would deliver a uniform dose with no possibility of an overdosage.

Because of the success of the earlier hyoscine studies and of the present experiments with atropine in obtaining systemic effects with intranasal administration, it would appear that consideration might be given to further investigation along these same lines. Wescoe et al[7] have already studied the effects of both of these drugs as antidotes for DFP; it is interesting to note that they used doses of 3 mg of atropine and of hyoscine given intravenously to cats and monkeys. In view of the differences in salivary production that the present series of experiments has demonstrated to exist between atropine and hyoscine, it is noteworthy that Wescoe's group appear to have used the drugs almost interchangeably.

Sollman[5] states that atropine has less of an antisialogogic effect than does hyoscine; this would help explain the differences noted in the action of the two drugs in the present series of experiments, and leaves open the possibility that on nasal application other (more desirable) systemic effects of atropine might be obtained as rapidly and completely as with hyoscine. That intranasal medication with atropine may lead to adequate absorption is further supported by the relatively high incidence of side effects after its administration in these studies.

In any consideration of the local application of these drugs to the nasal mucous membrane, it must be borne in mind that certain individuals may develop sensitivity reactions, especially after repeated doses. Further, in the experience of the present investigators more toxic reactions resulted from the atropine than from the hyoscine. Fortunately, the useful dose range of atropine is considerably larger than that of hyoscine, as the lethal dose of the former is greater than that of the latter; thus the usual clinical doses of atropine tend to be somewhat larger than of hyoscine.

SUMMARY

Using the depression of salivary secretion as a criterion, further studies were done on the systemic effect of intranasal hyoscine, and the intranasal absorption of atropine was also evaluated.

At 15 and 30 minutes following medication, there was significantly less absorption of hyoscine from the mucosa of both the nasal septum and the nasopharynx than from other parts of the nasal cavity. Later, the difference in absorption was no longer of statistical significance.

There was no significant difference in the systemic effect of hyoscine nose drops regardless of whether they were administered to the roof of the nasal cavity, to the floor of the nose, or directly to the inferior turbinate.

Subcutaneous injection resulted in the most rapid and complete absorption. Nose drops and nasal spray (in detergent) were intermediate in effect between the subcutaneous and the sublingual routes, being closer to the subcutaneous route in activity.

There was a trend for sublingual tablets to be absorbed slightly more rapidly and completely than oral capsules.

The addition of a detergent and of hyaluronidase to atropine nose drops had no effect on the rate or degree of absorption.

Atropine was found to cause less complete depression of salivary secretion than did smaller doses of hyoscine when subcutaneous and intranasal administration were compared. This is interpreted as reflecting a lower antisialogogic activity of atropine rather than a slower rate of absorption. More side reactions were noted with the atropine than with hyoscine.

Possible explanations for these differences are considered, and possible applications of the intranasal route for medication are discussed.

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LXXXVI

HEMIFACIAL SPASM: AN AFFECTION OF THE FACIAL NERVE

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The facial nerve is an integral part of the anatomy concerning the specialty of otolaryngology. Any pathology of this nerve requires careful consideration both in diagnosis and treatment. Facial tic and facial spasm are entities which have not been generally brought to our attention. Numerous papers have been published in the journals of neurology and neuro-surgery; yet these problems many times bring the patient to the office of the otolaryngologist. It is appropriate at this time to bring more recent aspects to your attention. There are factors which are changing and I would like to review these in the light of my interest in this subject.

Hemifacial spasm is a condition manifesting itself by clonic and occasionally tonic contractions of the musculature innervated by the facial nerve usually beginning in the orbicularis occuli and spreading to the other muscles supplied by the facial nerve. The contraction occurs at intermittent, irregular intervals; the patient cannot control it nor produce it voluntarily, although at times a trigger action such as blinking the eyes or blowing out the cheeks will cause the spasm. The type of contraction varies from severe sudden involvement of the entire group of muscles which may last several seconds or minutes, to minute quivering or twitching of any one muscle or associated group of muscles. The spasm may occur during sleep. It is a disease of adult life and does not occur in children; it is worse under stress or strain and it may occur with tic douloureux. Occasionally it may be bilateral, (1) although when it involves both sides, the spasms do not occur simultaneously (2) and are not of the same magnitude.

SYMPTOMS AND DIFFERENTIAL DIAGNOSIS

The term facial tic has commonly been used when referring to hemifacial spasm; however this is a misnomer since a tic differs from a hemifacial spasm fundamentally in origin, symptomatology and

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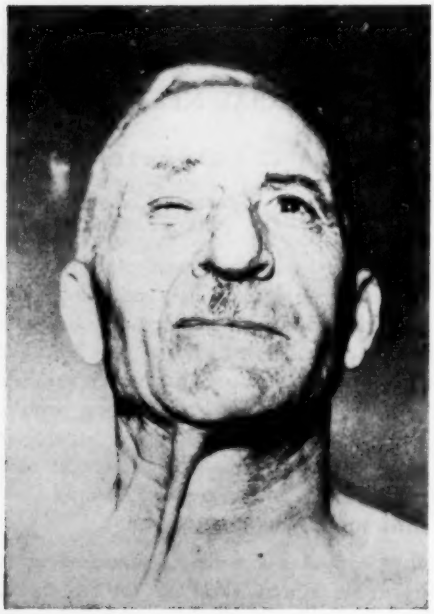

Fig. 1.—Photograph of patient during an intense hemifacial spasm involving platysma muscles. (Courtesy of Dr. R. Wartenberg.)

treatment. A tic is a compulsion neurosis, psychogenic in origin and its treatment is in the realm of psychiatry in which the condition is explained to the patient and a method is used to convert the tic into a more acceptable psychic symptom such as showing anger, talking loud, etc.

The two are readily distinguished by the following:

1) The spasm occurs in muscles ennervated only by the facial nerve whereas a tic usually includes other closely associated muscles such as the tongue, neck or larynx. The tic is a mass physiologic action and the spasm may be considered a limited anatomic motion.

2) The tic is associated with irresistable tension relieved only by performance of the act and with anguish should the urge to act be denied; whereas there is no compulsion to perform the spasm and no feeling of relief after it has been completed, or frustration if it is denied.

Fig. 2.—Patient who has had hemifacial spasm for eight years. In this photo the face is in repose. Note deepening of nasolabial groove on her left side.

Fig. 3.—Photograph of same patient as the preceding, during mild spasm which began in her left orbicularis occuli.

3) A tic is controlled by will. It is a motion which a patient can inhibit or start voluntarily; on the other hand the spasm is an involuntary action over which the patient has no control.

4) Hemifacial spasm may occur during sleep but a tic never occurs during sleep.

CLASSIFICATION

Hemifacial spasm may be classified into two types. First, the cryptogenic which manifests itself by the irregular, involuntary, contractions of the muscles supplied by the facial nerve, as just described, usually starting in the lower half of the orbicularis occuli and the orbicularis oris. This has also been referred to as idiopathic, essential, or primitive.

There is another type of spasm which occasionally follows some direct organic cause such as aneurysm of the basilar artery (Campbell[2]) or tumor of the petrous ridge (Miller[3]). This is referred to as secondary hemifacial spasm or postparalytic, as it may develop following a facial nerve paralysis. These are less severe in most instances than the cryptogenic and are easily differentiated by the history.

ETIOLOGY

The cause of both the cryptogenic and the postparalytic spasm is unknown. There have been numerous cases reported in which intracranial pathology has caused irritation to facial nerve or nucleus resulting in a spasm. These have been described as: aneurysm of the basilar artery; tumor of the petrous portion of the temporal bone; osteosarcoma; meningioma; neurofibroma; meningoencephalitis; encephalitis; carious teeth conjunctivitis and injuries of the seventh cranial nerve. It is interesting to review briefly some of the hypotheses which have been offered to explain the pathology and mechanism of this phenomenon.

Ballance[4] and Sullivan[5] were of the opinion that the disturbance was of central origin in the Rolandic motor area and the facial nucleus. Later Howe, Tower, Duel[6] and other workers presented experimental data showing that hemifacial spasm could exist with the entire cerebral hemisphere and Rolandic motor area removed which in the opinion of most observers precluded the hypothesis of central origin. In 1952 Wartenberg[7] offered an entirely different approach which he referred to as a release phenemonon. He postulates that the facial nucleus contains two motor systems: a) a lower system which produces the stimulus which causes the contraction of the facial muscles

Fig. 4.—Photograph of patient attempting to whistle, showing weakness of left facial musculature which develops in cases of long standing.

Fig. 5.—In this photograph the patient is trying to puff out her cheeks, but due to the associated movement of the orbicularis oris. the buccinator on the involved side contracts, thus preventing the patient from puffing her cheeks. If the lips were passively held, an attempt to puff the cheeks would be successful as no associated movement of the orbicularis oris would initiate the spasm.

and b) an upper system superimposed upon the lower. In common facial paralysis both systems are damaged. When restoration occurs the lower is first to recover as it is phylogenitically the older and stronger. The upper system has not yet recovered and since it is the inhibitory or restricting neuron, the lower system functions at random. In hemifacial spasm only the upper motor neuron is damaged. This system being the younger phylogenitically allows the lower neuron to cause the spasm. It is interesting to otolaryngologists that rhythmic contractions of the soft palate, pharynx, larynx and other neighboring structures are at times associated with hemifacial spasm and viewed by some as another example of the release phenomenon (Schultz,[9] Lachmund,[10] Urechia,[11] Foix[12]).

One other explanation for this phenomenon which seems plausible is suggested by Woltman[13] et al., and would tend to explain the improvement of spasm by neurolysis.

Clinical experiences would lend credence to this theory. Williams, Lambert and Woltman[14] reported seven cases of hemifacial spasm and one of blepharospasm in which neurolysis or facial nerve decompression was performed. The results are interesting and significant, as in all cases the spasm disappeared in a few days: however, in six of the cases it returned within several months; in the two cases in which the spasm did not return, one patient had a complete facial paralysis and the other developed a psychogenic deafness. One of the important aspects of their report was that thickening of the nerve sheath near the stylomastoid foramen was present. The findings at operations of their cases are as follows:

Case 1) A 2 mm fibrous nodule was attached to the inner nerve sheath at the stylomastoid foramen.

Case 2) The facial nerve sheath was tough and resistant to cutting.

Case 3) A tough fibrous envelope was present for 5 mm at the stylomastoid foramen.

Case 4) Normal in appearance.

Case 5) At the Pes Anserinus the nerve was thick and definitely resisted the knife.

Case 6) The entire nerve sheath was unusually thick and resisted the knife.

Case 7) Marked thickening of the nerve sheath for a distance of one centimeter at the stylomastoid foramen.

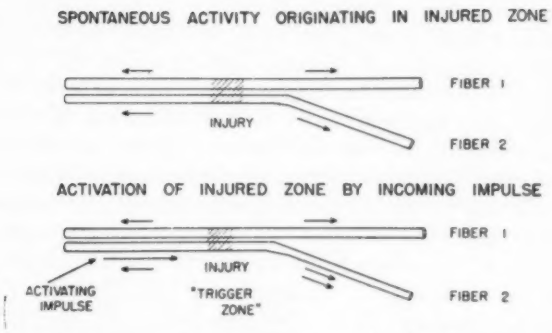

Fig. 6.—Fibers 1 and 2 represent axons of the facial nerve innervating the upper and lower parts of the face, respectively. Local injury to the nerve by compression and ischemia in the facial canal is indicated by cross hatching. Upper diagram: Spontaneous discharge of impulses (the arrows) from the injured zone produces spasm or contracture. Lower diagram: During interparoxysmal periods, nerve fibers in the injured zone are hyperexcitable. The action current of a "voluntary" impulse in fiber 2 acts as a trigger to the injured zone, causing a discharge of impulses in both fiber 1 and fiber 2, whereas only the impulse in fiber 2 was willed. Synkinesis results from this interaction between nerve fibers. (Courtesy of H. M. Woltman.)

Case 8) Essentially normal in appearance—this sheath was injected with normal saline before incising.

Williams[15] in a recent personal communication has advised me that all his operative cases are now over two years and the final results of nine cases are: one case is completely free of symptoms; one case is almost symptom free; one case has a recurrence of symptom associated with upper respiratory infections, but at all other times he is free of symptoms; one patient is still free of symptom but has a partial facial palsy. This is the case in which the nerve sheath was injected with saline before splitting.

In summarizing, five cases had a short period of relief but then the spasm reappeared as bad as it was before the operation. This gives three good results and one fair one out of nine.

Howard House[16] performed a neurolysis on a patient with a persistant blepharospasm. The following day the patient was relieved from the spasm and has not experienced its return since. In his case there was no visible abnormality in the facial sheath.

In correlating the experimental and clinical data, certain patterns are formed which suggest to one that a common denominator is present which may cause both facial spasm and Bell's palsy. It is

generally conceded that vasospasm, thrombus or embolus may cause ischemia due to damage to the facial nerve and sheath in the fallopian canal and would tend to give adequate explanation of the precipitating cause of Bell's palsy and hemifacial spasm. It is believed by most observers that the vasospasm is due to a dysfunction of the autonomic nervous system; in some instances a physical allergy to cold. Regardless of what the reflex pattern might be to explain the mechanism of hemifacial spasm, it seems logical to assume that tissue damage does occur from the ischemia. This is particularly evident in Williams series of cases where fibrous tissue was present in the nerve sheath near the stylomastoid foramen and House's case where a neurolysis gave immediate relief. This same pathology has frequently been reported by other observers in Bell's palsy (Kettel[18]).

Etiologic factors such as aneurysm of the basilar artery, although rare, do occur. It is therefore of the utmost importance to rule out any possible organic lesion which may be present. This is done by stereoscopic x-rays of the skull, angiograms, tomograms and electroencephalograms. In addition, it is advisable to obtain neurologic consultation in any case where intracranial pathology is suspected.

TREATMENT

The treatment of hemifacial spasm is difficult. One must not underestimate the disability caused by the irregular spasm which acts as a constant aggravation to the psychic distress of the patient.

Nonsurgical treatment may alleviate the symptoms for a short period of time but clinical experience and reports of other observers indicate that this is of little value. On the basis of vascular spasm as a possible etiology the following agents have been suggested for early treatment: a) sedation; b) vasodilators as nicotinic acid or ronicacol; c) intravenous procaine.

Swan[19] reported two cases of Bell's palsy which were relieved by blocking the stellate ganglion. This would seem logical to perform in an early case. Wartenberg[7] suggests an agent which acts centrally like panparnit and artane. The agents are similar and act in blocking the proprioceptive impulses and diminishes the motor impulses to voluntary muscles.

Since non-surgical treatment has contributed little to the relief of the patient, we must resort to surgery as the method of choice. Two procedures are suggested: 1) Nerve section of the branch or branches of the facial nerve at the periphery that appear to be most productive of the spasm. This procedure has been advocated by Lathrop. 2) Neurolysis in which the sheath of the facial nerve is

incised. Great care must be taken to explain the unfortunate sequelae of this treatment such as facial paralysis, tinnitus or decreased hearing. Even though a facial paralysis is disfiguring, many patients prefer it to the severe, paroxysmal contracture associated with the facial spasm.

Section of the nerve trunk at its exist from the stylomastoid foramen has been performed in the past but due to the obvious, immediate complete paralysis this is to be mentioned only to be condemned or to be performed after all other methods have been exhausted and the patient is desperate.

The cause of hemifacial spasm is unknown; the mechanism is still debatable, and the treatment is at best speculative. It is my desire in presenting this paper to create more interest among the otolaryngologists in this unusual subject as it is in this field of otolaryngology that the patient is usually first seen and it is here where the subsequent treatment will be carried out.

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LXXXVII

THE IMPORTANCE OF CERTAIN CONSONANTS IN ESOPHAGEAL VOICE AFTER LARYNGECTOMY

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We know that the inability to speak, consequent to the total removal of the larynx, forms a serious psychic trauma. Therefore it is of the utmost importance for the personal and social revalidation of such patients that they learn a new technique as soon as possible. In the far greater number of these cases an efficacious speech treatment meets with success in a short time.

As we learned from the experience with 36 laryngectomized patients, operated upon in the Groningen University Clinic by Prof. Dr. Eelco Huizinga, speech therapy should commence as soon as the artificial feeding is stopped. Precious time may otherwise be lost, in which the patient may become depressed or too well accustomed to buccal whispering. Regular contact with patients who already speak, especially in this period, is of the greatest importance.

Extralaryngeal speech with voice is achievable by using the esophagus (and possibly the hypopharynx) as an air-reservoir and as a pseudo-glottis. For completeness' sake we also mention here "parabuccal speech" (van Gilse[1]), very seldom met with, in which one cheek is used as an airbag and a "glottis" is formed somewhere between cheek and molars. With esophageal speech, however, normal conversational speech is more closely approached.

As it is not always possible to locate the place where the voice originates, the voice may be pharyngeal or esophageal. In patients whose esophagus is ascertained to be an air-reservoir, the pseudo-glottis is often found on a level with the esophageal orifice (Beck,[2] Seemann,[3] Weiss and Grünberg,[4] Moolenaar-Bijl[5]). In the x-ray films of one of our patients, (taken by Prof. Keyser, Director of the Radiological Institute) the stenosis is plainly visible in the mouth of the esophagus (Figs. 1 and 2). In Figure 2 the vagueness of part of the

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Speech Therapist, in the Department of Logopedics of the Oto-Rhino-Laryngological Clinic, University of Groningen.

Fig. 1.—Neck organs in repose after the swallowing of a contrast-mass.

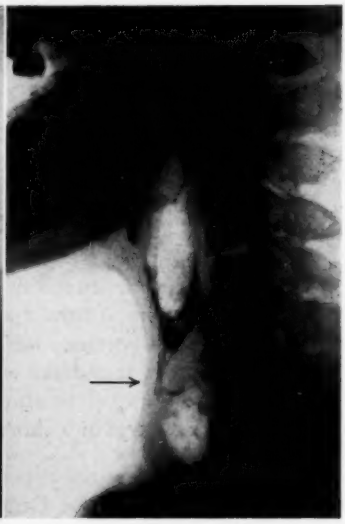


Fig. 2.—Stenosis in the mouth of the esophagus acts as pseudo-glottis during phonation. Vibration visible on the skin of the neck.

front line is caused by the vibrations of the skin during phonation. This is almost certainly the place of the pseudo-glottis.

The mechanism of bringing air into the esophagus was formerly designated as "swallowing air." Already as early as 1924, however, Gutzmann[6] mentioned "aspiring" as a possibility, and since then many authors noted this in patients who had achieved fluent esophageal speech (Seemann, Beck, McCall[7]). Dahmann[8] pointed out that with normal persons the upper part of the esophagus expands with inspiration. If the esophagus opens during, or immediately after, inspiration, air will stream in. With laryngectomized patients phonation and tracheal breathing therefore should not be entirely dissociated, contrary to what H. Stern[9] formerly recommended. Keeping up the normal connection (inhaling before speaking) as much as possible proved to us to bring about the best results.

Thanks to Prof. Dr. M. N. J. Dirken, Director of the Physiological Laboratory, to whom we are gratefully indebted for his co-operation and enlightenment, we have been able to fix a few items about

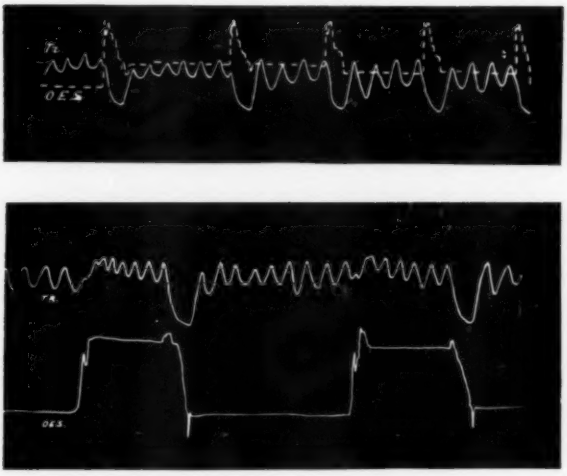
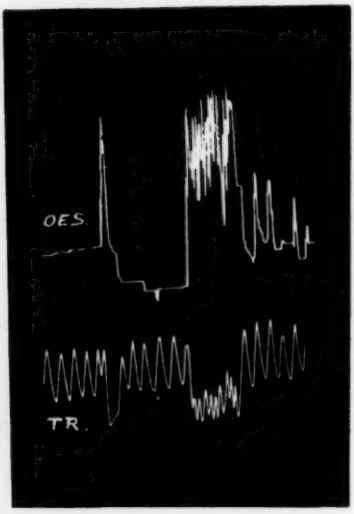


Fig. 3.—*a*. Esophageal phonation coincides with tracheal deep expiration. Patient who uses the swallowing method. *b*. While the air is being retained in the esophagus the tracheal breathing continues. Phonation again coincides with deep expiration.

the relations of respiration and voice production with two of our well-speaking patients, a man and a woman. Their tracheas and mouths (and noses) were fastened to a spirometer by means of a plaster mask. The male patient was in the habit of swallowing air into the esophagus; his phonation each time coincided with a deep expiration; in repose the curve of the esophagus remained horizontal (Figs. 3a and 3b). On the x-ray screen we consequently saw that the esophagus remained shut when the patient did not speak. In the case of the female patient the reverse is seen: the tracheal and esophageal curves are constantly paralleling each other, in speaking and in silent breathing. The intake of air into the esophagus coincided with inspiration, the phonating of one or two syllables with expiration (Fig. 4a). When the patient held her breath for a few seconds without phonating, the esophagus lost only little air and was again filled up with the next deep inspiration (Fig. 4b). On the x-ray screen it could be seen that the esophagus also contained air when in repose. With this patient there was no question of swallowing movements. The mechanism which we might with Moore[10] call "direct inhalation," had arisen spontaneously within two weeks after the operation.



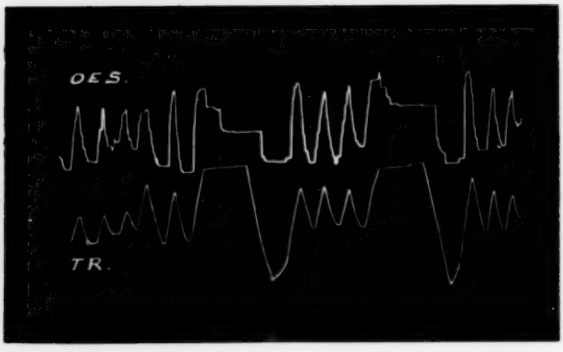


Fig. 4.—*a*. Patient with direct inhalation. Tracheal respiration movements run parallel to esophageally spoken syllables. Esophageal air movements runs parallel to tracheal breathing. *b*. Same patient as Fig. 4*a*. While the air is being retained in the lungs the esophageal curve also shows a plateau.

Though these two patients produced a fluent and clear speech, we have come to the conclusion that neither swallowing nor inhaling is the best method. Swallowing interrupts speech audibly after every six to ten syllables and is tiring; Moore and other American authors even consider the habit of swallowing "detrimental to good esophageal speech." Inhaling makes breathing superficial and frequent and causes "ballistics," while the speech expires in syllables.

The third method consists of insufflating air into the esophagus by means of a small movement of the mouth. Air is thus brought in unobtrusively and quickly. This requires less energy and interrupts flowing speech much less than swallowing does; it makes speech more smooth and more continuous than inhaling does.

The visible movements, serving to bring in some air before starting the voice, consist in just closing the lips or touching the tongue against the hard palate. This kind of movement resembles a very slightly articulated *p* or *t*. Further back in the mouth, in the place of the *k*-articulation, a movement of the back of the tongue may have the same effect.

A possible connection between consonant formation and the intake of air into the esophagus was first brought to our attention by our best esophageal speaker. About half a year after his operation he demonstrated to us that he could easily repeat the syllable "pah" some 40 times consecutively. Experimenting further we found practically the same for "tah" and in a slightly less degree for "kah" as well. The syllables "mah" and "lah" to the contrary he could only say 7 times at the utmost; then he had to take in new air into the esophagus as well as into the lungs. (This patient when speaking keeps up the maximal expansion of the thorax as long as possible). We drew the conclusion that the pronunciation of *p*, *t* and *k* makes it easier to take air into the esophagus, and that perhaps the two may even coincide. Also the fact that this patient can speak a short sentence with many liquids in it but once, without a second intake of air (e.g. "Have you ever been in England or in Wales?"), but is able to repeat a sentence containing many voiceless plosives several times quite easily (e.g. "The skipper of the packet-boat took a cup of coffee in the cockpit"), renders it plausible that those consonants play a part in the aspiring of air. An x-ray examination for which we are greatly indebted to Prof. Keyser, corroborates this supposition.

On the x-ray screen we see the following: In repose the esophagus is entirely closed. At the same moment the patient is going to pronounce a series of syllables "mah," the esophagus is filling with air, and empties itself gradually during the pronunciation of six times

A *B*

Fig. 5.—*A*. Same patients as Figs. 1 and 2. Esophagus filled with air at the beginning of a series of syllables "mah." *B*. After 6 syllables "mah" the esophagus is empty.

"mah" (Fig. 5a and 5b). On pronouncing a series of syllables "pah," the esophagus fills up with the first *p*. Then we see the walls giving way a bit with each *a*, expanding themselves maximally again with each *p*, so that after 15 syllables "pah" (or more) the air volume is exactly as big as it was at the beginning (Figs. 6a and 6b). If "pahpahpah" etc. is pronounced very slowly we see that each protracted *a* takes nearly all the air and every *p* restores it again.

In order to render still more clear the importance of *p* for aspiration, a photograph of the esophagus was taken at the moment that an isolated voiceless *p* was being formed. Here too we see the esophagus, closed when in repose, filling itself with air when the *p* is being articulated (Figs. 7a and 7b).

As far as I have been able to ascertain, this phenomenon has been mentioned in the literature only sporadically and casually. Stetson[11] says: "Gradually this independent movement of insufflating air becomes fused with the consonant closure of a phrase. . . . Increasing the rate of a series of words with *p*, *t* or *k*, will force the subject to use the same movement for intake that he uses for the consonant." Moore says: "The tongue is placed in the position used at the start of a D-sound. With the nasal port closed the tongue is lifted and retracted, thereby forcing some of the air which is in the mouth and pharynx into the esophagus. It is the only place where it can go." Moore calls this the "injection method;" he, contrary to us, prefers "direct inhalation."

We have followed up this advantage of the consonants *p* and *t* for producing esophageal voice. We dropped the swallowing method and always started speech treatment with the syllable "pah." It proved that nearly all our patients could much more easily form words with voiceless plosives (such as cat, cook, pipe, pack), than isolated vowels or words beginning with a vowel, which was the classic starting point in the air swallowing method. After these we very soon pass on to words of two syllables, especially those with the accent on the second syllable (e.g. tattoo, concoct, propel, compact). As soon as the patient has gained some skill, he can without difficulty form initial vowels. These are preceded by the above described aspiring movements. To avoid a word with initial vowel making the impression of beginning with *p* or *t*, the movement of aspiration should be made very lightly and not quite joining the word.

Though in many publications attention has been drawn to the fact that skillful esophageal speakers aspire air and do not swallow it, one gets the impression that in Europe little benefit for therapy has hitherto been gained from it. Only Marland[12] indicates that

A B

Fig. 6.—*A.* Esophagus filled with air at the beginning of a series of syllables "pah." *B.* After 15 syllables "pah" the volume of air has not diminished.

A *B*

Fig. 7.—*A*. When in repose the esophagus is empty. *B*. At the moment of the articulation of a voiceless "p" the esophagus fills up with air.

learning to aspire air should immediately be started by means of pumping movements with the throat. In the American literature at our disposal we found that aspiring air should be exercised by training the muscles of thorax, neck and pharynx (even before operation according to McCall).

We think, however, that these intricate methods are not necessary as a rule. The simpler we set about it, and the more quiet and relaxed the patient, the quicker he will achieve a clearly intelligible esophageal speech. Soda water, which Luchsinger[13] to whom we owe an extensive study on speech without larynx, recommends, we have never applied. The patients who without difficulty can produce a belch, can as easily pronounce a syllable with *p* or *t*. The first phase of the ructus, as described by van Gilse,[14] is thus substituted by a real element of speech. Those who cannot produce a ructus at will should, voicelessly, practice syllables with *p* and *t*, until after a short time esophageal voice originates.

SUMMARY

Speech therapy of laryngectomized patients should be started as soon as possible after operation. Of 36 patients, operated upon in the Groningen University Clinic, 30 obtained reasonable to very good (pharyngeal-) esophageal speech; 3 have a little voice but not sufficient for conversation; 3 have continued to make shift with buccal whisper. Curves show two ways of aspiring air: "direct inhalation" and "injection." Roentgenograms show the filling up of the esophagus in "mah," "pah" and "p." The intake of air occurs preferably by "injection." The necessary tiny movements may coincide with the articulation of certain initial consonants (voiceless plosives). In speech therapy these consonants should be used as a starting point to stimulate the intake of air into the esophagus in a natural way.

Academisch Ziekenhuis.

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LXXXVIII

AUDITORY TRAINING FOR THE PRE-SCHOOL HARD OF HEARING CHILD

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Auditory training may be defined as a process of making sounds meaningful. It is not a new concept among those who teach the aurally handicapped, but there are a number of aspects of such a program which many writers have long felt, in view of recent developments in electronics, needed revision, elaboration, or modernization. Current language development programs for the pre-school aurally handicapped child are becoming concerned with providing maximum benefits in listening, through the use of a hearing aid which has been selected at the earliest age feasible. With this in mind, a number of questions and answers will be presented which will form the framework of a good auditory training program.

How Severe Must the Hearing Loss of a Child Be Before Auditory Training is Rejected? The writer believes that all children who demonstrate any remnant of hearing as tested by a pure tone or speech audiometric test should be considered candidates for auditory training. There are a number of reasons why children who demonstrate minimal residual hearing on their first recorded test should be given the advantage of auditory training.

First, the child may not be responding at threshold during the test situation, but rather at a level well above his actual threshold. Though the PGSR has been described as an objective test designed to eliminate the need for such apparent procrastination, the writer feels that its present state of development does not warrant full confidence in it. For this reason, the reliability of audiometric tests on pre-school children must be measured not only by PGSR but also by other conditioned response techniques and startle responses to pure tone and speech audiometry. In one clinic valid repeated tests made before, during and after an auditory training period for poorly co-operative youngsters, one to three years of age, have shown original scores depressed ten to twenty decibels. Co-operative youngsters, two to

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four years of age, who were tested monaurally showed a depression of original thresholds of five to ten decibels. If these findings tend to hold true for other centers, then auditory training should be instituted.

Second, there is a paucity of research regarding intelligibility scores for very young hard of hearing children, and research studies should be carried out with children as well as adults. This implies that many more of the so called "deaf" children will be receiving auditory training for research purposes as well as language development. The end result will be a better understanding of methodology in the language development programs of aurally handicapped children.

The third reason for early auditory training relates to the importance of sound for purposes of keeping in touch with the environment and for warning signals. Ramsdell[2] appropriately suggests that, "We stop our car, not because someone says 'policeman' (the symbol for the officer), but because we hear the shrill sound of the whistle." Experience with auditory training classes has proved that most children who demonstrate any residuum of hearing are capable of very gross sound discrimination. Hence they can be taught the differences between the train whistle, the car horn, a door slamming, a dog barking, a whistle, etc. Such discrimination will not only keep a youngster in touch with his environment, but will serve the very useful function of attention to warning signals for self preservation.

At What Age Should a Child Enter Into an Auditory Training Program? If we accept the idea that all pre-school hard-of-hearing children should be given an auditory training program if any hearing is demonstrated and approval from the otologist has been given, then we imply that all age groups are eligible. Although auditory stimulation for children under twelve months of age is certainly warranted, the techniques for such training will require a somewhat different approach from that suitable for youngsters one year or older. In any event, it is desirable that an auditory training program be started with children at the earliest age feasible. If maximum benefits from hearing could be provided as early as one year of age, then language development could more closely approximate that of the normally hearing child.

Although the majority of hearing aids selected by the writer and her colleague have been for children between the ages of two and four years of age, one instrument was selected for a fifteen-month-old boy who was tested at one year of age and enrolled in the auditory training program at thirteen months. Specific information relative

to language development, speech, and voice characteristics of these very young children given appropriate training with aids does not appear in the literature at present.

We have good reason to believe that many hard of hearing children given maximum benefits in hearing at an early age will be capable of attending regular school where education and language growth will be in a much more normal environment. Numerous surveys in this country and abroad have demonstrated through audiometric testing that approximately 97% of children in schools for the deaf have usable residual hearing. If these children could be given adequate training through amplification during their pre-school years, we could anticipate that future education of many would not require special state and private schools for the deaf. This would be a substantial saving of the public's money.

How Long Should a Child be Enrolled in an Auditory Training Program? If we divide the program into two phases: 1, amplification with a group unit for purposes of a hearing aid selection, and 2, auditory training with the individual aid for purposes of language development, we find the first step to be extremely important but less time-consuming. The initial portion of the training has been found in one center to require on the average four to six weeks of one-hour sessions five days a week. The child is then ready for a hearing aid and is encouraged to wear it throughout the day. The practice of providing auditory training for thirty minutes a day over a period of years as is done in many schools for the deaf seems a most illogical and unenlightened approach to teaching language to hard-of-hearing children if the auditory avenue of approach is to be considered the primary one. Normally hearing children require at least the first year of life to develop a very limited vocabulary and perhaps a minimum of two or more years before rudimentary sentence construction begins to take form. It would appear most improbable that the severely aurally handicapped child would develop much language if given auditory training through daily listening periods of thirty minutes. The ultimate goal should be maximum benefits through listening, and then a language development program which parallels that of normally hearing youngsters.

Should Auditory Training Precede Speech Reading? The writer believes that speech reading should be used by the aurally handicapped for purposes of communication, but only as an adjunct to what he hears. If one considers the art of speech reading as one means of communication, gesture as another, and hearing as another, then the logical place to begin language training would appear to be with

maximum use of hearing as experienced by normally listening infants. Once sound becomes meaningful through specific daily training using a hearing aid, then that which cannot be interpreted through listening alone should be augmented by speech reading. At this stage of the language development program the auditory and visual stimulation should be presented as a functionally interactive unit.

What Should be the Qualifications of a Teacher Engaged in an Auditory Training Program? It appears that the person teaching in an auditory training program must be exceptionally well informed to do an adequate job. Advances in audiology and allied fields are continuing, requiring constant perusal of the literature. It is evident that too many teachers of the deaf apply the traditional methods while attempting to utilize modern electronic equipment. It is essential that they break with such well known techniques as the teaching of the elements through visual, tactile and kinesthetic methods and become more familiar with the dynamic concepts of audiometry, hearing aids and their use, medical aspects of hearing, speech therapy, voice science and language development of the normally hearing child. Diagnostic techniques, hearing aids, and theories of rehabilitation have changed and are still changing, but too few of the teachers keep pace with the advances.

What Part Should the Parents Play in an Auditory Training Program? Mothers and fathers need to have some introduction to audiology which will better help them to understand the nature and extent of their childrens' hearing losses as well as the prognosis for the development of speech and comprehension. Providing an insight into the physiological, psychological and educational problems of the hard-of-hearing child gives a parent more security in his new endeavor of educating an exceptional child, and a real challenge to help overcome the handicap. In many centers, at least one parent is required to observe or participate daily in the auditory training program in order that he may carry out the objectives at home which have been demonstrated in the classroom activity. On the whole, better results in the selection of a hearing aid, as well as subsequent language development, has been obtained from those children whose parents have given full support to a home training program.

Auditory training in the modern sense is concerned with providing maximum benefits in listening through the medium of electronic devices. We must begin to think of all aurally handicapped children as having some residual hearing unless reliable audiometric methods have shown the contrary. The implication presented has been that children who demonstrate any hearing may derive con-

siderable though varying degrees of benefit from amplification. Auditory training as early as possible is the key to such benefit and this training should utilize the best of modern instrumentation administered by well trained, professional personnel. Such therapists must recognize the fact that hard-of-hearing children can be taught to listen and discriminate only if they get hearing through amplification all day long as does a normally hearing child. If such a plan proves its worth through research training programs, then many more aurally handicapped children will be entering regular public schools rather than schools for the deaf, at six years of age.

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LXXXIX

DIAGNOSIS AND EARLY TREATMENT OF LESSER FACIAL FRACTURES

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Injuries of the face frequently result in fractures of the facial bones. The bones are thin and the skin covering provides only slight cushioning against trauma. Many of these injuries are slight, with pain or transitory swelling of the underlying tissues as the principle symptoms. If fractures are present, they may frequently be unrecognized on initial examination. Functional and cosmetic impairment resulting from incomplete reduction may not become apparent for some weeks or months, when treatment becomes more difficult. It is with the diagnosis and early treatment of these lesser facial fractures that this paper is concerned.

As used in this paper, lesser facial fractures refer to fractures of the midportion of the face, without intracranial or occlusal involvement. The structures affected include the nasal bone, the nasal septum with its bony and cartilaginous components, the maxilla and maxillary sinus, with the exception of the palatine and alveolar portions, the zygoma (malar bone) and zygomatic arch, the entire orbital border, the lacrimal bone, the inferior turbinate, portions of the ethmoid, and, in addition, the anterior plate of the frontal sinus. Excluded from consideration are transverse fractures and craniofacial disjunction, fractures of the facial bone with cranial complications, and mandibular or maxillary fractures which affect the occlusion.

Early treatment refers to reduction of fractures within approximately thirty days after injury, before union has occurred. Omitted from consideration are old, healed fractures with deformities which may require secondary plastic or reconstructive procedures.

SIGNIFICANCE OF LESSER FRACTURES

Although physical changes are usually present in lesser fractures, their significance may be unrecognized. More serious injuries may

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require immediate attention. Often soft tissue edema obscures the fracture. Sometimes the injuries may at first appear trivial, especially in children. As a result, several weeks may elapse before any noticeable deformity is observed. In children, as developmental changes ensue, not only do these distortions become apparent, but aberrant growth of cartilage and bone may result in cosmetic disfigurement and functional impairment.

The reported increase in motor vehicle and sports accidents has been reflected in facial injuries, and particularly in fractures. Straith[1] who has long dealt with the problem arising from motor accidents, reported that among 372 persons injured in automobile accidents, 248 or 69 per cent were riding in the front seat next to the driver. Of these, more than half suffered head injuries. In another study, he found that 35 out of 50 consecutive patients, with head injuries requiring plastic surgery, were women who had occupied the front or "death seat." Competitive sports involving forceful bodily contact, such as football, basketball and hockey, have resulted in many facial injuries. Facial injuries also frequently result from falls in the home and from industrial accidents.

There is evidence that many facial injuries produce fractures which are unrecognized at the time. For example, in army training camps it has been observed that some men are unable to use gas masks because of nasal obstruction. While the causes may have been congenital in some cases, many were the result of old, untreated facial injuries.[2] These are the more common deformities which may result from lesser facial fractures: subluxation of the columellar portion of the septum with asymmetry of the nares; twisted, humped or depressed nose, often resulting in a pugilistic or "tough" appearance; flattening of the prominence of the cheek; and downward displacement of the orbital contents, causing ocular asymmetry.

Although these fractures do not result in severe immediate damage, important functional disturbances of the following systems may eventually ensue:

1. *Respiratory.* Nasal obstruction due to septal deviation, depression of the nasal dorsum, or external deviation of the nasal pyramid.

2. *Olfactory.* Impairment of the sense of smell due to damage or obstruction of the olfactory organs.

3. *Visual.* Diplopia resulting from the downward displacement of the orbital contents, due to comminution or trauma to the floor or lateral wall of the orbit, with involvement of the suspensory ligament.

4. *Masticatory.* Interference with mandibular movement caused by depression of the zygomatic arch against the coronoid process.

5. *Neurological.* Facial anesthesia resulting from trauma of the inferior orbital nerve.

6. *Psychological.* Facial deformities causing negative psychological reactions, varying from introversion to overt belligerence. These reactions may even result from mild deformities.[3] Disfigurement leaves its imprint on the personality as a result of social, psychological and economic rebuffs. While individuals vary in their response nearly all are adversely affected.

Most, if not all, of the damaging sequelae enumerated above might be avoided if lesser fractures were promptly treated. It is therefore necessary to diagnose facial injuries adequately, and to be sure that fractures are absent before decision is made against treatment. Whenever a lesser fracture is diagnosed, it should be treated without unnecessary delay. Although painstaking care may be needed in many cases, the effort will be well rewarded by favorable results, and the avoidance of future operations.

REVIEW OF RECENT LITERATURE

During the past few years there has been increased interest in the early treatment of facial fractures.

Hipskind[4] has reviewed the procedures for reduction of zygomatic bone fractures. He presents an outline for a comprehensive examination of the zygomatic area, and includes details of the history, the condition of the patient, and the results of palpation of the malar-zygomatic area. Hipskind summarizes a number of recognized methods of reduction, including those of Gillies (temporal), Goldthwaite (buccal), and Patterson and Gill (direct facial), as well as reduction through the nasal and antral routes. He also adds a modification of his own for the zygomatic arch fractures. After infiltrating with local anesthesia, a 6/0 fish-hook with barb removed, is passed below and curved behind the zygomatic process. Traction is applied and may be sustained by attaching the eye of the hook to rubber bands looped around a tongue blade incorporated in an elastic bandage head dress.

Fomon[5] and his associates have experimented for several years with open methods of reduction for nasal fractures. In a recent paper, they advocate the wider use of open reduction, describe in detail the procedures they follow, and point out the advantages:

first, an accurate diagnosis by inspection; second, precise reduction under direct vision; third, evacuation of effusions and better drainage; fourth, correction of pre-existing defects; and fifth, attention to associated fractures, lessening the danger of postoperative deformity and impairment of function. Fomon feels that since the approach to open reduction is through rhinoplastic technique, the method is best suited for men trained in this technique. He and his associates believe that to attempt correction by blind reduction, which involves using force in reverse of that which caused the fracture, often serves to aggravate the damage. They also state that blind re-alignment of the fragments by unlocking and disimpaction, while more effective, still lacks the assurance of precise reduction. They conclude, therefore, that open reduction of practically all nasal fractures is the method of choice. However, they exclude simple fractures of the osseous vault and nasal fractures in children, which they reduce by the closed method.

Other rhinofacial surgeons do not share this preference for open methods of reduction. Maxwell[6] uses open reduction only when a good appearance and functional result cannot be obtained by the closed method. For accurate diagnosis he recommends bimanual palpation, supplemented by visual inspection simultaneously, and x-ray studies. He recognizes the possibility of psychosomatic influences related to facial fractures, and suggests psychiatric consultation, when necessary, for reassurance of the patient.

Hersch[7] discusses the importance of the structure of the nasal bony vault in the mechanism of fracture and repair. The nasal bones are thin and flat, and are sandwiched between two adhesive layers—the mucoperiosteum internally, and periosteum and skin externally. The muscular pull on them is negligible, the bones serving only as contour supports. Experimentally, Hersch prepared a model of the nasal bony arch with dental compound, and applied adhesive tape to each surface. When this arch was cracked, the deformity could be corrected by re-aligning the fragments; and he found that the arch was able to maintain its proper shape because the adherence of the fragments to the covering or lining, or both, kept them in place. He believes that in the living subject, the periosteal attachments of the bone are so firm that it is rare for the fragments of the comminuted bone to be stripped of both layers. Thus, with the fragments of the shattered parts attached to one layer or the other, they may be manipulated and fitted back into their respective places within the arch. The ridge pole, that is, the perpendicular plate of the ethmoid, is unimportant for preservation of the bony arch. There is no tendency for the deformity to recur, and the arch maintains itself without

mechanical support. Its failure to do this may be traced to incorrect alignment. Hersch classifies nasal fractures into two main types, depression and lateral displacements. In a series of 130 nasal fractures of all types, 40 per cent were depressions and 60 per cent were lateral displacements.

Becker[8] analyzes his experience with 100 cases of recent nasal fractures. He contends that although early reduction is desirable, favorable results have been achieved in cases reduced within two to three weeks, and occasionally after longer periods. He recommends exploratory reduction in children, under general anesthesia, when fracture is suspected but cannot be proved. He believes that the use of external and internal splints will minimize deformities of the alar cartilages and septal deviations, by preventing hematoma formation.

McLemore[9] has attempted to standardize the routine of diagnosis and treatment of facial fractures. He includes the following as facial bones: single bones—mandible, vomer, ethmoid, sphenoid and frontal; paired bones—maxilla, zygoma, nasal, palatine, lacrimal and inferior turbinate. Since the maxilla, the palatine bone and the zygoma are so firmly attached at their suture lines, he suggests that in the study of fractures, they may be considered as one bone. He feels it is well to start the operative procedure with local anesthesia, but with an anesthetist on hand in the event that the procedure becomes too extensive. He uses block and infiltration local anesthesia, and recommends an endotracheal tube when general anesthesia is necessary. From a study of the literature and from his own experience, McLemore believes that any method of treating a fracture of the maxilla, which does not involve a Caldwell-Luc approach, may be considered inadequate. He mentions that in the treatment of fractures of the arch and zygoma, he has found that a large orthopedic hook introduced into the temporal fossa of the zygomatic arch, and passed beneath the fragments, is satisfactory when traction is applied.

Cottle[10] and associates have reported the use of hyaluronidase in rhinoplasty and in recent fractures of the nose and septum. They found that the use of this enzyme lessened distortion of the soft tissues, and facilitated diagnosis and reduction of deformities. For local anesthesia of the external nose, they used a solution of 125 units of hyaluronidase to 25 cc of 1 per cent procaine with 0.5 cc of 1:1000 epinephrine hydrochloride.

Kanthak,[11] in reporting on the treatment of fractures of the middle third of the face, discusses the relationship of the bony struc-

tures of the face. He states that these are thin "eggshell" types of structures, which do not lend themselves to customary methods of reduction and fixation. They are also frequently associated with severe injuries, with more or less mental confusion and brain damage. He feels, therefore, that the patient may not receive adequate medical care in this area. These bones heal rapidly and may leave conspicuous deformities, which are difficult to correct at a later date.

Dingman,[12] in his discussion of the treatment of malunion fractures of facial bones, states that with the advent of antibiotics, he does not consider cerebrospinal rhinorrhea a contra-indication to realignment of facial bones. He adds that repositioning of fractures is frequently followed by early cessation of the rhinorrhea. Brown[13] shares this view. Both authors stress the importance of neurosurgical consultation in these cases.

In his paper on treatment of multiple fractures of facial bones, Walden[14] states that reduction and immobilization are also essential here, as in other fractures. He uses the nearest bony structure lying cephalad to the fracture for the support of the displaced and loosened fragments. Other recent writers[15] report experiences with similar cases.

Schjelderup[16] outlines three methods of reduction of zygomatic fractures namely, the Gillies approach through the temple, elevation through the antrum, and open reduction in old untreated cases or in severely comminuted fractures. These procedures may have to be assisted by interosseous wiring or external fixation, or both. In a series of 92 cases, the Gillies operation alone was used in 50 cases; the Gillies plus external fixation in 4; Gillies plus suture in frontal synostosis in 4; Gillies plus antral approach in 7; elevations from antrum alone, 3; open reduction, 18; bone graft elevation of depressed orbital floor, 4; and no treatment necessary in 2.

EXAMINATION PROCEDURES

Lesser facial fractures may occur as the result of slight or moderate facial injuries, or they may be associated with more severe injuries. Routine studies should include history, inspection, palpation and roentgenography, as described below. When more serious injuries are present, detailed examination for the lesser fractures, especially manipulative procedures, should be postponed until the patient's general condition permits.

History. The history of the accident will bring out much helpful information, and a full report on the circumstances of the injury should be obtained. The force and direction of the blow, and

the nature of the object involved, will often suggest the type of fracture to be sought. For example, a blow by a blunt object, such as a baseball or a fist, would produce local damage at the site of the blow; or, a severe blow such as might be encountered when a person is thrown against a dashboard, might be expected to produce more extensive damage, including the LeFort types of injury. On the other hand, a gunshot wound would produce severe comminution in the track of the missile.

Questions should also be asked in the history regarding loss of consciousness and hemorrhage. If the patient was unconscious for any period following the injury, or if persistent headache has resulted, intracranial injury must be suspected. If there is a history of severe, persistent epistaxis, damage to some of the larger vessels such as the sphenopalatine or ethmoidal arteries must be considered. This would indicate fracture of the septum, cribriform plate, or turbinates. Facial pain or anesthesia may result from trauma to the infra-orbital nerve in fracture of the inferior orbital border. Difficulty in chewing is suggestive of fracture of the zygomatic bone or arch.

Inspection. Visual signs of facial fractures include edema, ecchymosis, displacement, epistaxis, trismus, and ocular asymmetry. A photograph is a desirable permanent record.

Edema will occur at the site of the injury, and will generally be in proportion to the severity of the impact. When subcutaneous bleeding occurs, the swelling may be more diffuse. Inspection will reveal only gross displacement of supporting structures, and even they may be temporarily obscured by edema.

Ecchymosis is usually most intense in the vicinity of impact. However, in many cases, the extravasation may extend over a wide superficial area, and hematomas may occur.

Epistaxis is an indication of mucosal tear, and usually results from compound fractures of the nasal pyramid. Trismus or impaired mandibular motion results from fracture of the zygomatic bone or arch. Ocular asymmetry is usually due to an orbital fracture. Cerebrospinal rhinorrhea or cranial nerve paralysis indicates that cranial damage is present.

The internal aspect of the nose is examined for edema, tissue laceration, hemorrhage, and displaced fragments of bone and cartilage. Edema and minor hemorrhage usually accompany nasal injury, and are not significant except as they may obstruct the air passage. Severe hemorrhage is evidence of injury to a large artery or

vein, usually the nasopalatine or ethmoidal vessels. Nasal obstruction, a major symptom of nasal fracture, may be due to fracture of the lateral walls of the pyramid, or of septal fracture or displacement.

Palpation. Palpation is perhaps the most important single diagnostic method, and may reveal tenderness, edema or induration, bony or air crepitus and bony displacement. Standing directly in front of the patient, both sides of the face should be palpated simultaneously, according to a standard routine. Using firm and gentle pressure the thumbs and finger tips are passed progressively over the bony areas in the following order: frontal areas, orbital borders, nasal pyramid, zygomatic areas, alveolar maxilla, and mandible. Areas of bone displacement and other abnormalities will be palpable. However, in areas where swelling is present, bone irregularities may not be discernable by palpation. In these cases, palpation should be repeated in a few days when the swelling has subsided.

X-ray Examination. Roentgen studies are essential for diagnosis and treatment planning of facial injuries, and are of medicolegal importance.

Roentgenography of the head is more difficult than for most other regions of the body. The interpretation of films is often less satisfactory because of the superimposition of bony structures.[17] Furthermore, fractures may be demonstrable by physical examination, and yet not be visible on roentgenograms. This may occur in nasal fractures with lateral displacement but without depression of the dorsum. Children are particularly poor subjects for facial roentgenographic studies. Thus, if a fracture is not revealed on the roentgenograms, the possibility of one being present is not to be ruled out.

While these reasons bespeak the need for care in the use and interpretation of roentgenographic data, they do not minimize the need for x-ray as a diagnostic tool. If the roentgenogram does reveal fracture, the evidence is conclusive, and the position of the fragments can usually be determined. In the zygomatic area, roentgenographic findings are reliable with respect to both the presence or absence of fracture. In the nasal pyramid area, positive evidence of fracture is conclusive, although negative roentgenograms may not be.

In the study of facial injuries several views are usually taken of each injury. The following are most commonly used:

Waters' view (posterior-anterior "nose-chin"). This is the most important single view and provides a general survey of the mid-

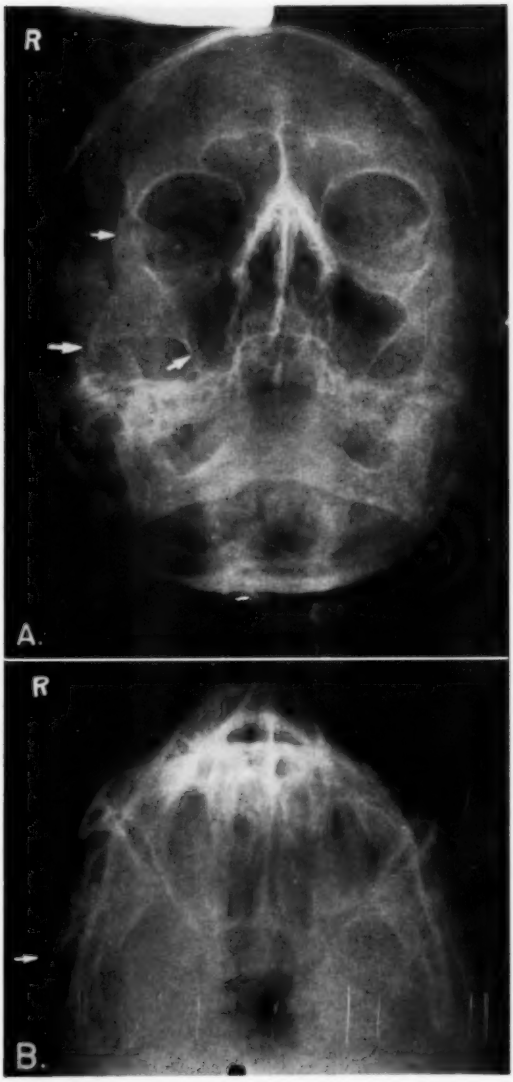

Fig. 1.—Depressed fracture of right zygomatic arch. A. Waters' view: Arrows indicate fracture positions of R. zygomatic articulations. B. Submentovertical view: Arrow shows depression of arch.

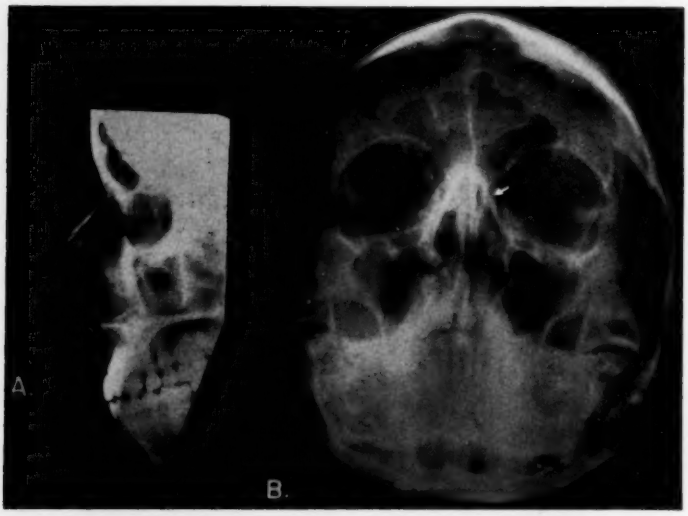

Fig. 2.—Nasal pyramid fracture. A. Soft tissue lateral view: Tip fracture of nasal bone with slight depression and multiple fractures of lateral wall. B. Waters' view: Medial displacement of left nasal wall at arrow.

facial region. It reveals the antrums, orbital borders, frontal sinuses and zygomatic arches. The nasal septum and lateral walls of the bony pyramid are also seen. Fractures in any of these structures will usually be shown (Fig. 1). Changes in the transverse diameters of the orbits are almost pathognomonic of orbital fractures; other findings indicative of fracture are clouding of the antrum or frontal sinuses, asymmetry of the zygomatic arches, or deviations of the nasal pyramid or septum. The asymmetry of normal and affected sides facilitates diagnosis.

Lateral View (*"soft tissue nose"*). Taken with the injured side toward the film, this view will visualize depressed fractures of the nasal dorsum, tip fractures of the nasal bone, and some linear fractures (Fig. 2). It does not reveal lateral displacement. The anterior nasal spine of the maxilla is also visualized. This view should be taken in all suspected cases of nasal pyramid fracture.

Occlusal View (*axial of nose*). This position is helpful in visualizing nasal fractures, and may reveal lateral deviations of the nasal pyramid and anterior nasal spine. Although this view is often

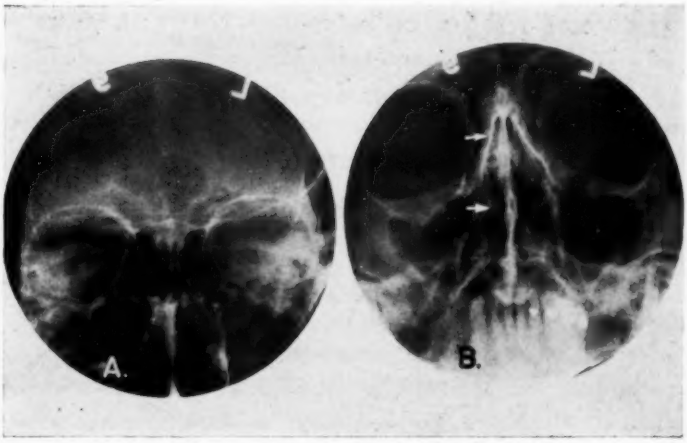

Fig. 3.—Roentgen appearance of patient with severe nasal obstruction following injury which had been untreated for six weeks. A. Caldwell view: Ethmoid sinus areas show no evidence of infection. B. Posterior-anterior view: Medial displacement of R. nasal bone and frontal process at arrows. Possible fracture of R. inferior orbital border. Slight clouding of antrum.

unsatisfactory, it should be attempted to supplement the Waters' and lateral views for nasal fractures.

The following additional views are frequently helpful:

Modified Waters' View (*extended Waters'*). This is taken with the neck extended, with the nose elevated more than in the conventional Waters' position. In cases of zygomatic fracture, it supplements the conventional Waters' view and helps visualize the position of the fragments.

Submentovertical (*basal view*). This is taken supine with the neck extended and a sandbag under the shoulders. It is useful in demonstrating fractures of the zygomatic arch and the anterior surface of the maxilla.[18] The individual zygomatic arch may be better visualized with the head turned slightly, usually to the contralateral side.

Caldwell View ("*nose-forehead*"). This view reveals the condition of the frontal sinuses and is useful in the study of the ethmoid region (Fig. 3).

TABLE I.

INDICATIONS FOR THE USE OF VARIOUS ROENTGEN VIEWS.

VIEW	INDICATIONS	BEST APPLICATION
Waters'	*All* nasal and zygomatic injuries	1. Antrum 2. Orbital borders
Lateral	*All* nasal injuries	1. Depressed nasal fracture 2. Tip fracture
Occlusal	Nasal injuries	1. Lateral deviation of nasal pyramid 2. Lateral deviation of anterior nasal spine
Modified Waters'	Zygomatic injuries	1. Zygomatic bone
Submentovertical	Zygomatic injuries	1. Zygomatic arches 2. Anterior surface of maxilla
Caldwell	Limited to septal, frontal sinus and ethmoid injuries	1. Frontal sinus 2. Ethmoid

With the development of a new compact hand stereoscope, greater usefulness is available for stereoscope Waters' and lateral views of the skull in the study of facial fractures.

In facial injuries, studies of the cervical vertebrae should be taken as a precaution when pain symptoms cannot readily be explained in terms of known injuries. Several investigators have reported fractures of the cervical spine resulting from injuries of the "whip-lash" type.

Comparison of the effectiveness of various x-ray positions for the visualization of lesser facial fractures is summarized in Table I.

CLASSIFICATION OF LESSER FACIAL FRACTURES

Classification is usually based on the severity of the fracture, that is, whether simple, compound or comminuted,[19] as in other areas of the body. However, there are several differences in facial bones. There are more than a dozen small bones in the face, and since the facial bones articulate by synarthrosis, it is understandable why frac-

tures of individual bones are infrequent. Multiple facial fractures are the rule rather than the exception. Another difference between facial bones (except the mandible) and long bones is in the effect of muscle pull. In long bones, which are subject to muscle pull, comminuted fractures are far more difficult to treat than simple fractures. Due to the slight amount of muscle pull in the nasal pyramid comminuted fractures in these areas are relatively easy to treat. Traction is rarely necessary to prevent shortening of the bones. For these reasons this broad classification of facial fractures must be supplemented for complete diagnosis. Classification of nasal fractures has also been atempted on the basis of the direction of impact.[20] The directions usually described are frontal, lateral and inferior. The line of displacement of fractured bones is determined by the direction of the blow. However, the direction of the force is not always clearly defined. Furthermore, the severity of the fracture depends on the severity of the blow, rather than on its direction.

For convenience, lesser facial fractures may be divided topographically into two areas—the nasal pyramid area and the zygomatic area. The nasal pyramid area includes the nasal bones, the frontal process of each maxilla, and the bony and cartilaginous structures of the septum. These septal structures include the perpendicular plate of the ethmoid, the vomer, the septal cartilage, and the upper alar cartilages. The turbinates, lacrimal bone, the paper plate of the ethmoid, the lower alar cartilages, and the anterior spine of the maxilla, along with the columellar portion of the septum, should also be included. The zygomatic area includes the zygoma proper with its four processes, the zygomatic arch, the inferior and lateral borders of the orbit, as well as the maxillary sinus. Excluded from the scope of this paper are fractures of the face resulting in cranio-facial disjunction, and fractures with occlusal or cranial complications.

In the nasal pyramid area the following fractures are more commonly encountered:

1. *Linear fracture*—Simple fracture of the nasal bones without displacement.

2. *Greenstick fracture*—Incomplete fracture of the nasal bone or the septum.

3. *Simple depressed fracture*—Simple fracture of one nasal bone or frontal process depressed into the nasal fossa.

4. *External deviation*—Moderately severe fracture of the nasal pyramid with lateral displacement; the septum is commonly involved.

5. *Depressed frontal fracture*—Severe depression of the nasal dorsum with crumpling of the septum, often with impaction of fragments.

6. *Septal injuries*—Displacement or fracture of the septal cartilage or bone.

In the zygomatic area the following fractures are more commonly encountered:

1. *Zygomatic arch fracture*—Simple depression, usually occurring near the articulation of the temporal and zygomatic bones.

2. *Displacement of zygoma*—Moderately severe fracture with the direction of displacement depending on the direction of the blow.

3. *Comminuted zygomatic bone fracture*—Severe fracture, frequently impacted with the orbital floor and the maxillary sinus affected.

DIAGNOSIS OF SPECIFIC FRACTURES

Linear Fracture. This is a fracture without displacement through the nasal bone, the nasofrontal process, or the septum. There is usually a history of a mild or glancing blow on the nasal dorsum, such as a playful blow with a fist, or an inadvertent bump into a door. In these cases, epistaxis is absent or mild, and as a rule, there is no loss of consciousness.

There may be a moderate amount of external nasal swelling. Ecchymosis of the eyelids is often due to subcutaneous hemorrhage. Intranasal inspection may reveal nothing abnormal, or a mild degree of swelling, or slight bleeding.

Tenderness over the site of the blow is usually present, with a moderate degree of swelling and induration. The septum is not displaced. No bony crepitus would be palpable, although air crepitus may be noted, especially if the paper plate of the ethmoid area is fractured.

Although the clinical effects are mild and treatment is often unnecessary, roentgen studies are taken in order to confirm the diagnosis and to rule out other fractures. A soft tissue lateral view of the nose usually shows this linear fracture, but without evidence of displacement in the dorsal margin. An occlusal film is desirable in order to show that the nasal structures and the septum are in good position. A Waters' view is valuable to rule out fractures through the antrum or orbit.

Fracture may occur through the tip of the nasal bone or at the junction of the nasal bone with the frontal process of the maxilla. The fragments are in good alignment. There is no comminution or displacement. The nasal mucosa is undamaged.

Greenstick Fracture. This type of fracture is due to a bending of the nasal bones or septum, or of the frontal processes, and is not a through and through fracture. There is usually a history of a moderately severe blow with a blunt object to the side of the nose, or a fall. These fractures occur most commonly in children. Epistaxis is usually absent and there is no loss of consciousness.

Lateral deviation of the nose or mild curvature of the septum causes asymmetry. Edema is moderate but may be sufficient to mask the deviation for a few days. Usually there is slight ecchymosis at the site of the blow. Intranasal inspection of a septal greenstick fracture will reveal a septal deviation which at times is marked by mucosal swelling, or which might be interpreted as an old deformity. Nasal obstruction may be present as a result of deviation of the septum, edema or submucosal hemorrhage. However, the mucosa will not be pierced by bony fragments.

There is tenderness and swelling over the site of the fracture. If seen very early, a depression may be noted over the site of the blow. Bony crepitus would not be noted, and in most cases, air crepitus would be absent. Upon intranasal examination, movement of the septum might be elicited if forcible pressure is made with a heavy applicator, nasal speculum, or elevator.

X-ray films usually show no abnormality,[8] and are made primarily to exclude more serious involvement. The Waters' position helps to rule out depression of the lateral pyramidal wall, involvement of the antrum or orbital margin. The lateral view would exclude depressions of the nasal bone or tip fractures. However, an occlusal film may show displacement of one wall of the pyramid at the fracture site. Since in children occlusal films are difficult to obtain because of the smallness of the nose, their value is questionable.

The bending of the nasal bone usually occurs at its articulation with the frontal process. In these fractures, the bend is inward. Bowing of the septum occurs in the cartilaginous portion, and is concave toward the blow. The mucosa is intact.

Simple Depressed Fracture. This is a fracture of one nasal bone or frontal process, depressed into the nasal fossa. It is usually

due to a rather sharp lateral blow or fall. Slight or moderate epistaxis may occur, but there is usually no loss of consciousness.

Immediately after the injury, a definite depression is noted over the side of the nose. Within a short while swelling of the nasal dorsum might obscure the depression. Ecchymosis on the side of the injury, involving the eyelids, may be present. Upon intranasal examination, a narrowing of the nasal fossa may be noted, due to depression of the nasal bone. Evidence of bleeding may be noted from a mucosal laceration at the site of the injury. The septum is usually intact.

Tenderness and depression or edema are noted over the lateral nasal wall. Both bone and air crepitus are usually absent.

X-ray examination in the Waters' position may show a medial displacement of the pyramidal wall, and help to rule out fractures of other bones. The occlusal view may show medial displacement of the nasal bone or the frontal process on the side of the injury. The depression may occur anywhere along the lateral nasal wall. There is usually a clean break, with one fragment depressed. The septum is not involved.

External Deviation. This is a fracture displacement of the nasal pyramid, with depression of the frontal process and the nasal bone on the side of the blow, and with overriding of the frontal process and nasal bone on the opposite side. This is probably the most common of the nasal pyramid fractures. There is a history of a rather severe lateral blow by a fall or by a blunt object, such as a baseball bat or a fist. Epistaxis is present and may be profuse; it is due to tearing of the mucosa by bony fragments. If the blow has been severe enough, there may even be a history of a mild loss of consciousness, indicating concussion.

The nasal pyramid shows a definite lateral displacement. Swelling, ecchymosis, and hematoma may obscure the degree of displacement. Ecchymosis of the eyelids or subconjunctival hemorrhage are usually present. Intranasal inspection shows bloody discharge and partial obstruction by bone or cartilage fragments. The septum may be fractured in both its bony and cartilaginous portions, and displaced to the opposite side of the blow, or even to the same side. Edema of the mucosa would add to the obstruction.

Upon external palpation with the thumb and fingers, a deviation would be noted. The amount and degree of edema and hematoma of the soft tissues is quite variable. Movement of the fragments can be elicited. The sharp edge of the frontal process is pal-

pable on the depressed side. Movement of the cartilaginous septum might also be elicited. Intranasally, a fracture or hematoma might be palpable on the septum.

X-ray examination in the Waters' position shows the degree of asymmetry of the bony nasal pyramid. Displacement of the septum may also be demonstrated. At times, however, because of the superimposed bony shadows and markings, this asymmetry and displacement may be difficult to visualize. Stereoscopic films are of advantage. Clouding of the antrum indicates evidence of damage to the mucosal lining. The lateral view of the soft tissues of the nose may show a fracture of the midportion of the nasal bones when these are comminuted. However, when the pyramid is displaced en masse, the lateral view may show no evidence of fracture. The occlusal film may also show the degree of lateral displacement of the frontal processes and the nasal septum.

There are several variations in the fractures occurring in lateral displacement. Nasal bones may override one another, or they may both be displaced in the direction of the blow. In the latter case, the nasal bone on the ipselateral side underrides its frontal process, and the nasal bone on the contralateral side overrides its frontal process. Fracture of the nasal bone occurs below the glabella. The frontal process of the maxilla usually fractures at its base, or along the suture with the nasal bone. Lateral displacement may result in underriding of the proximal maxillary fragments on one side and overriding on the other side. The nasal septum is fractured or displaced.

Depressed Frontal Fracture. This is a depressed comminuted fracture of the nasal pyramid with broadening of the nasal base lines and flattening of the dorsum. There is usually a history of a direct frontal blow or fall. An example might be a dashboard injury, or one resulting from an assault with brass knuckles. Severe epistaxis usually occurs, and there may have been a momentary loss of consciousness due to concussion. Rhinorrhea or coma are indicative of intracranial complications.

The nasal dorsum is flattened and the inner canthi often appear spread apart. Swelling will appear rapidly, and may be extensive. If several hours have elapsed since the injury, ecchymosis of the eyelids and nasal dorsum will be visible. Intranasal inspection reveals evidence of bleeding and compounded fracture of the septum, with possibly loose fragments in both fossae.

There is swelling and induration over the nasal dorsum, and a flattening of the bony and cartilaginous structures can be detected

on firm but gentle palpation. Sharp, bony fracture lines will be felt when the nasal bones are impacted between the frontal processes. These fractures will yield to pressure of the nasal speculum. The comminution is evidenced by bony crepitus, and occasionally, air crepitus may be noted.

On x-ray examination the lateral view shows: (1) depression of the pyramid and degree of comminution; and (2) the level at which the profile line is fractured, and its proximity to the glabella. The Waters' position will show involvement of the orbital borders and the antra if present. Clouding of the antrum nearly always indicates hemorrhage, and is strong evidence of fracture. The Waters' position also shows the degree of depression of the lateral walls of the pyramid and buckling of the septum. The occlusal view may show the position of the fragments relative to the lateral walls and septum.

The fracture usually occurs below the glabella, and involves many of the nasal pyramid structures. The nasal bones may be depressed and locked under, or may override the frontal processes. Fragments tear through the mucosa and project into the nasal cavity, and the septum has comminuted fractures. The maxillary sinus is frequently involved.

Primary Septal Injury. This section is concerned with primary septal injuries, previous sections having described septal fractures associated with other nasal fractures. In any injury to the nose, damage to the cartilaginous structures must be considered. This is particularly true of the septum, which may be dislocated, displaced, bent or fractured. Children are especially prone to septal injury.

Depending upon the severity of the blow, there may be displacement of the septal cartilage with external deviation of the lower dorsum, or fracture of the anterior nasal spine. In more severe cases, there may be fracture of the perpendicular plate of the ethmoid, as well as of the cartilaginous portion of the septum; and this force may be transmitted to the cribriform plate producing intracranial trauma and cerebrospinal rhinorrhea. There may be laceration of the soft tissues of the nasal tip, or there may be through and through tears with avulsion of the alar cartilages. These injuries are usually due to a blow received from below, as in a fall.

Dorsal deviation, asymmetry of the nares, soft tissue trauma and avulsion may be seen externally. Intranasal examination reveals mucosal discoloration, edema, and the extent of septal displacement and obstruction. Mucosal edema may obscure septal hematoma,

which present themselves as a medial bulge, obstructing one or both fossae.

The columellar border of the septum may be displaced from its articulation with the anterior nasal spine and vomeric groove. The anterior nasal spine may be movable, and bony or cartilaginous crepitus might be noticeable. Swelling over the nasal dorsum will be noted if the nasal bones are involved.

Roentgenograms are taken to rule out other fractures. The Waters' position may demonstrate any involvement of the orbital borders or of the maxillary sinuses. In severe cases, where the perpendicular plate of the ethmoid is involved, or where there has been a telescoping of the nasal bones into the roof of the nasal fossae, a Caldwell view should be taken to rule out fracture of the frontal sinus or of the cribriform plate. A lateral view may reveal a fracture of the nasal spine, and an occlusal view may also be taken to show lateral deviation of the nasal bones.

Hematomas will usually result from cartilage fractures which have not lacerated the mucosa, and untreated hematomas will frequently produce liquefaction of the cartilaginous septum. This will often result in the loss of support of the cartilaginous dorsum just above the tip, and produce a saddle type nose. Avulsion of the alar cartilage usually occurs at the junction of the lateral and medial crura. Subluxation of the columellar border produces asymmetry and obstruction of the nares. Fracture of the anterior spine may lead to retraction of the base of the columella, and fractures of septal cartilage may override one another.

Zygomatic Arch Fracture. This is a fracture in the region of the zygomatic arch. It is usually due to a fall or a sharp lateral blow to the side of the face with a hard object. There is no history of bleeding.

There is visible depression over the zygomatic arch area. However, if several hours have elapsed and hematoma or swelling has occurred, depression may not be visible. If displacement of the arch is severe, with impingement against the coronoid process, there will be pain and impaired movement of the mandible.

Palpation will reveal tenderness or depression over the zygomatic arch area. Intra-oral palpation may reveal displacement of the zygomatic arch against the coronoid process, and may also show restriction of space between the zygoma and the maxilla.

In the Waters' position, showing both arches on one film, fracture depression may be noted on the affected side. The submento-

vertical view, with the head slightly rotated to one side, usually away from the injury, demonstrates the depression more effectively because the complete arch is shown.

Fractures usually occur at the zygomatic-temporal articulation. Pain and difficulty in mastication are usually due to trauma and pressure of the depressed arch against the masseter and temporal muscles or coronoid process of the mandible. Differential diagnosis of the zygomatic arch fracture from the zygomatic bone fracture is based on the location of the fracture. Zygomatic arch fractures occur only in the arch. If any other articulation of the zygoma is affected, the diagnosis is zygomatic bone fracture.

Fracture Displacement of the Zygoma. This is a depression and disarticulation of the zygomatic bone. There is asymmetrical flattening of the face due to a blow over the cheek. This may result from assault or from an accidental kick or blow in football or similar sports. The patient will report pain and numbness in the cheek and impaired mandibular motion. Nosebleed will occur on the affected side, and diplopia may be reported.

There may be flatness of the upper cheek and swelling below this area. Ecchymosis of the eyelids and subconjunctival hemorrhage are present on the affected side. There may be impaired motion of the eye or displacement of the eyeball. Intranasal examination may reveal blood in the middle meatus on the affected side, due to hemorrhage into the antrum from a mucosal tear.

The injured zygoma is depressed, and the lower cheek is swollen. Both the involved and the uninvolved orbital borders should be palpated simultaneously to demonstrate the asymmetry. Fractures usually occur at all of the four suture areas of the zygoma. Palpation will reveal the direction of the displacement. There may actually be a step-off at the points of fracture and difficulty in movement of the jaws. Bony movement will be discernable unless the fracture has been impacted. There is usually tenderness on palpation at the fracture sites. Swelling and induration will often prevent satisfactory palpation during the first few days following injury.

Roentgenological examination is of great importance in this condition because it is the most dependable diagnostic procedure. Since the direction of displacement cannot be established by inspection or palpation alone, the Waters' and extended Waters' views are of greatest value because they show most of the borders of the zygomatic bone. The submentovertical view reveals the anterior surfaces of the maxilla. Together, these views help visualize the position of

the fragments and their relationship to one another. They show whether the zygomatic fragment is displaced above or below its junction with the maxilla, or at its junction with the frontal or temporal bones, and will thus aid in proper interpretation of the deformity. Successful treatment of zygomatic fractures depends upon a full understanding of the relationship of the fragments. Stereoscopic views are especially useful for these fractures.

The zygomatic bone is usually fractured at or near all of its four articulations, which occur with the frontal and temporal bones and in two positions with the maxilla, at the inferior orbital border and the anterior wall. The body of the zygoma is rarely fractured. Anatomically, the body of the zygoma is heavy and its articulations are rather fragile. The zygoma is usually pushed downward and inward, and is frequently impacted. The occurrence of visual disturbances, such as diplopia, indicates that the region of attachment of Lockwood's ligament at the fronto-zygomatic area has been involved. Anesthesia of the face is due to damage of the infra-orbital nerve, and impaired mandibular motion is due to involvement of the mandibular musculature.

Comminuted Zygomatic Bone Fracture. This is a depression and comminution of the zygomatic bone. There is a history of a severe blow to the antero-lateral portion of the cheek. This may be due to a severe fall, to a severe blow with a blunt object, or to a windshield or dashboard injury. If loss of consciousness occurred at the time of injury, skull fracture may be present. Severe nosebleed may occur, due to injury of the maxillary sinus. The patient will complain of anesthesia of the face, of trismus, blurring of vision, and possibly of lacrimation and diplopia.

Severe swelling occurs over the cheek, with hematoma and ecchymosis of the soft tissue. Because of the swelling, depression may not be noted over the face. Difficulty of movement of the lower jaw will be evident, and epistaxis occurs on the injured side. Discoloration of the eyelids and of the eyeball may be present, as well as enophthalmos due to depression of the orbital contents. In extensive compound fractures, the bone damage can usually be visualized through the wound, which usually penetrates the maxillary sinus.

Tenderness and bony crepitus of the fragments may be demonstrable. There may be air crepitus of the soft tissues of the face due to air escaping into the tissues from the antrum. Intra-oral palpation may reveal lacerations of the buccal mucosa and sharp fragments of bone along the canine wall of the antrum or under the anterior root of the zygomatic arch.

Waters' and submentovertical views are needed in this injury, as in fracture displacements. Due to fragmentation of the anterior wall of the antrum, the relationship of the various fragments is difficult to interpret. Damage is extensive, involving the antrum and frequently the nasal pyramid. Lateral and occlusal views are therefore valuable.

There is usually a shattering of the zygomatic bone and fragmentation of the articulating structures. When the orbital rim or floor is splintered, the orbital contents may drop into the antrum, producing asymmetry or enophthalmos. In other respects the pathology is similar to, but more severe than, that which occurs in fracture displacements.

TREATMENT PROCEDURES

Since lesser facial fractures often occur in association with other injuries, careful observation of the general condition of the patient is necessary. The most serious or dangerous conditions must receive attention first. The patient must be checked for possible respiratory obstruction, hemorrhage, shock, intracranial or cervical spine damage, and other serious bodily injuries. Respiratory obstruction may be due to laryngeal trauma associated with head injury, to aspiration of blood, or to a mandibular fracture, with resultant muscular pull against the epiglottis. Retraction of the tongue, bronchoscopy, or tracheotomy, may be necessary to relieve the obstruction. Hemorrhage resulting from damage to the large vessels of the face and neck may be severe. These vessels should be clamped and ligated, if possible, and the blood loss replenished by transfusion. Prompt measures should be instituted for the treatment of shock. Intracranial injury may be manifested by loss of consciousness, temporary or persistent coma, paralysis, cerebrospinal rhinorrhea or otorrhea, aural bleeding, or other evidence of brain damage. When these injuries are noted, a complete neurological examination should always be made. The paranasal sinuses should be observed for signs of infection.

As a general rule, when intracranial or other severe injuries are present, manipulation procedures should be delayed until the patient's general condition permits. However, the presence of facial injuries should serve as a reminder that the examination for lesser facial fractures is necessary. At times, reduction of facial fractures may be accomplished without harm to the patient, while other major surgery is being performed.

Reduction of facial fractures should be performed as early as possible, ordinarily within twenty-four hours. If there is consider-

able induration or edema obscuring the fracture sites, or if the patient's general condition is such that it prohibits manipulation, reduction may be postponed for several days. Reduction should be attempted within eight days, if possible, before fusion of the bony elements occurs. If treatment is delayed more than several weeks after injury, refracture may be necessary before reduction can be accomplished.

Reduction of fractures is a painful procedure, and adequate anesthesia is essential for effective treatment. Local and topical anesthesia with novocaine, cocaine or pontocaine, are preferred for lesser facial fractures, except when extensive damage is present. General anesthesia is frequently used in children, and may also be necessary for tense individuals, or when the time required for extensive repairs is prolonged beyond the limits usually recommended for local or topical anesthesia. For adults, intravenous sodium pentothal is used. When general anesthesia is administered, aspiration of nasopharyngeal contents should be prevented[21] by packing the nasopharynx or by the insertion of an endotracheal tube.

Only a few instruments are required for reduction and these are usually readily available. For pyramid area fractures, the usual instruments are nasal speculum, bayonet forceps, straight and curved elevators (thin and sturdy) and Asch septum forceps. The elevators and Asch are covered with thin latex rubber tubing. For cases with partial bony union, a mallet, block and straight septum chisel are also needed. For reduction of zygomatic area fractures, the instruments selected depend upon the approach used. Most commonly used are elevators, a heavy towel clip or hook, and curved sounds. For open methods, appropriate knives, forceps, sinus punches and periosteal elevators are used.

All wounds should be thoroughly cleansed and carefully debrided in order to remove foreign bodies, detached fragments of bone and devitalized tissue. The administration of a booster injection of tetanus toxoid or a prophylactic dose of tetanus antitoxin is necessary in all cases of contaminated wounds. Penicillin and other antibiotic or chemotherapeutic agents should be given when infection is present or anticipated.

In externally compounded wounds, bony or cartilaginous fractures are reduced before the soft tissues are repaired, except where major damage has been sustained by the soft tissues. Early and adequate immobilization of the fractures is essential.[22] In instances of severe comminution, the use of retention appliances may be neces-

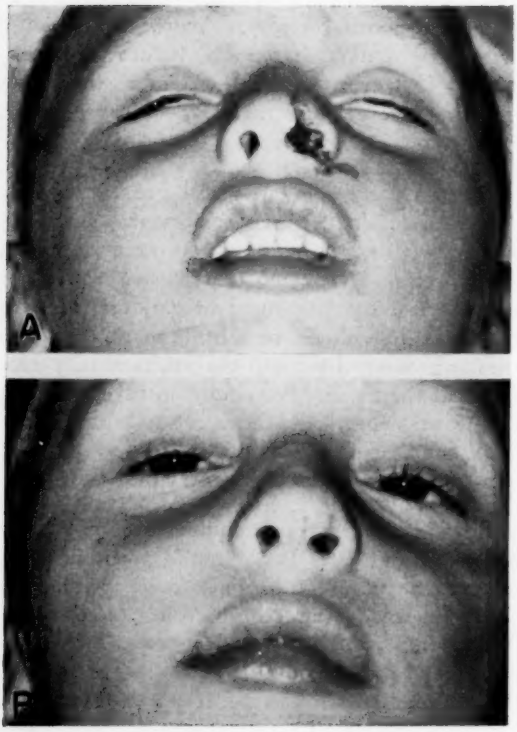

Fig. 4.—Immediate repair of alar avulsion. A. Complete separation of L. ala apex and base of naris, occurring after fall from bicycle. Bony pyramid intact. Wound repaired within four hours after injury. Order of suturing: Alar border, vestibular lining, cartilage and outer skin. B. Postoperative appearance nine days later. Contour of ala restored; notches absent; nares symmetrical; scarring minimal (Compare Fig. 5).

sary until healing has taken place. Protective splints are used in most cases.

When avulsion or other severe damage of soft tissue is present together with fractures, repair of the soft tissue has priority over bone reduction. Usually both may be done at the same time. However, if a choice is necessary, it is preferable to repair the soft tissue first, and thus achieve a good cosmetic effect at the expense of delay in reduction of bone, rather than the reverse. Delayed reduction of bony fragments in these cases will often not prevent good end

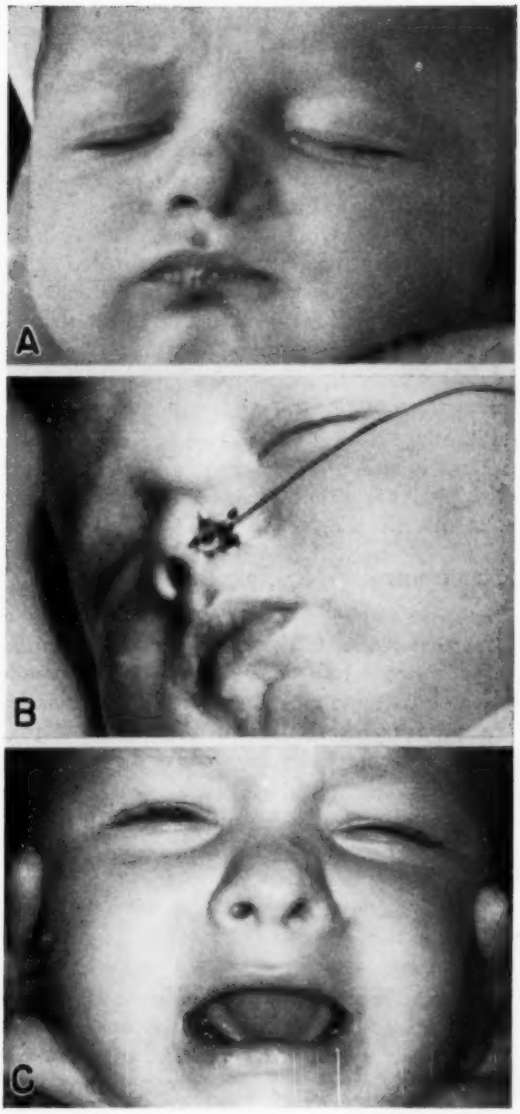

Fig. 5.—Cicatricial atresia following birth trauma. A. Appearance at six weeks. Complete atresia of L. naris; alar cartilages destroyed; extensive scarring of dorsum. B and C—Stages in repair. Fig. C taken ten months after A. L. nostril functional without prosthesis, soft tissues improved. Further plastic reconstruction probably necessary (Compare Fig. 4).

results. Whereas, it is much more difficult to effect a delayed correction of ugly, cicatricial formation of skin, cartilage and soft tissues.

Care in the repair of the alae and other natural orifices and folds of the face will minimize heavy scarring and retraction of the healed wound (Fig. 4). To prevent notch formation, the edges of the orificial wounds are sutured first in order to achieve good approximation of the borders. The vestibular lining of the nares is sutured separately from the skin covering. Best results are achieved in other areas of the nasal dorsum, when the tissues are sutured in layers from within outward. The periosteal, muscular and subcutaneous tissues are closed in this order with fine silk or catgut. The derma is approximated with subcuticular sutures, and the epidermis is sewn with closely spaced fine silk or nylon sutures. The skin sutures should be removed in three to five days.

When antibiotics are administered soon after injury, the danger of infection is minimized. However, when treatment of the soft tissue wounds is delayed, secondary infection may result, with undesirable scar formation (Fig. 5).

REDUCTION OF NASAL PYRAMID FRACTURES

Linear Fracture. In most cases, reduction is not required for these minor fractures because they are in good alignment. Cold compresses may be applied for one or two days to reduce edema. If there is a large hematoma near the fracture site, it is removed by aspiration. Intranasal packing and an external mold may be used to minimize further edema and recurrence of hematoma.

Greenstick Fracture. It is usually necessary to complete the fracture before reduction can be accomplished. This is done by applying pressure in the direction of the original injury, that is, to the concave side of the bone and septum. After the fracture is completed, reduction is performed by the same method described below for external deviations of the nasal pyramid. An exploratory reduction is attempted in cases of suspected greenstick fracture.

Simple Depressed Fracture. This is reduced by intranasal manipulation with an elevator. The site of the fracture is measured externally on the elevator, which is then inserted to the measured depth intranasally and the fracture is raised into position. At the same time, the fingers of the free hand exert counter pressure and guidance externally over the fracture area. These maneuvers are continued until good alignment is achieved. The fracture may snap into place during elevation, and will remain there without further fixation. Packing may be necessary if the fragment does not remain in situ.

External Deviations and Depressed Frontal Fractures. Treatment of these conditions is similar and may be described together. These fractures require elevation and manipulation of the both sides and the center of the pyramid, followed by reduction of the nasal bones, frontal processes and septum. If the fragments are impacted, they must first be released.

The success of manipulation depends upon proper interpretation of the pathology. Relative position of fragments should be visualized before instituting manipulative procedures. If blind reduction is attempted, further splintering and spicule formation will often occur, thus affecting the smoothness of the contour after healing has taken place.

Release of impaction is the first step. The fracture must be mobilized before it can be reduced. This can usually be accomplished by manipulation and lifting with an elevator, or by inward or outward rotation, followed by elevation with an Asch forceps. When the nasal bones are impacted between the frontal processes of the maxillae, the maneuver of Metzenbaum is applicable.[23] Lateral pressure, with the thumbs against the base lines of the bony nasal pyramid, will slightly evert the distal borders of the frontal processes, and permit elevation of the impacted nasal fragments. If none of these procedures are successful, it may be necessary to make a small stab incision over the glabella, and free the bones with a small chisel. Another alternative is open reduction by the intranasal rhinoplastic approach.

The second step is elevation and straightening of the septum. An elevator is inserted intranasally, and the nasal bones are raised. This will usually raise the fractured septum. With lateral pressure against the convex side of the septal deviation, the septum will usually snap back into position if the deviation is slight. If the septum is dislocated, it is grasped with an Asch forceps and lifted back into position in the groove of the vomer. If there is considerable overriding of the septal fragments, it may be necessary to slip the elevator between the fragments and pry them into position.[24] In these latter cases, gut sutures through the perichondrium will assist in retaining the septum in place.

Fragments of nasal bone and frontal process are then reduced. Remodeling of the nose may usually be accomplished with the fingers, and where the fragments are loose, this can be done directly. If the dorsum is fractured and deviated, and the base is intact, reduction is accomplished by raising the entire dorsum and setting it in position over the base. If the base is also fractured and displaced, the order

Fig. 6.—External deviation of nasal pyramid following blow with baseball bat. A. Twenty-four hours after injury. Depression over L. pyramid slight ecchymosis and swelling. Reduction procedure: L. nasal bone raised with straight elevator to release impaction. L. frontal process rotated into position using Asch forceps. R. nasal bone raised and rotated from R. frontal process, which it overrode. B. Postoperative view one-half hour after A. Nasal obstruction relieved; external symmetry restored. C and D—Frontal and lateral views of protective dental compound shield applied over flannel. Note: X-rays shown in Fig. 2.

of reduction depends on whether one or both sides of the base are fractured. When only one side is fractured, the dorsum on that side is first fitted into position by elevation, while the base on that side is rotated (Fig. 6). In cases where both sides of the bone are fractured, the dorsum is elevated to reduce the frontal processes. Thereafter, the nasal bones are fitted into position.

Although the nasal pyramid may remain in position if the fractures are properly reduced, a slight new blow may again disrupt the contour. It is therefore important to pack the nose with petrolatum gauze, and to apply an external splint or shield of dental compound plaster or metal. A protective layer of flannel is inserted under the shielding material, or adhesive tape may be used. The tape is applied snugly to reduce edema and hematoma formation. Among the various splints devised are those of Aufricht,[25] Roberts,[26, 27] Perlman,[28] DeKleine[29] and Brown.[13] Packing, when used for simple fractures, is removed the first day; in the more complex cases, in three to four days. The splint is used for three to four days in the simple cases, and for seven to ten days in the more complex. In rare instances, where mobilization and comminution have been unusually great, the wire sling of Brown may be employed. He passes stainless steel wire through both lateral walls of the pyramid and septum. One wire is placed through the upper portion of the pyramid and the other somewhat lower. The ends of the wires on the same side are twisted together over thin lead plates, producing a sling for maintaining the fragments in position. Other recent appliances for retention have been devised by Straith,[30] Kazanjian,[22] Erich,[31] and others,[32] to maintain the fragments in position.

Where additional support is required to maintain a comminuted septal fracture in the midline, dental wax insertions on both sides of the septum are retained by mattress sutures.[8]

Septal Injuries. Hematomas may sometimes be evacuated by aspiration. However, an incision is usually made along the anterior vertical and the inferior horizontal planes. The tip of the resulting angular flap is excised and the clot is removed. Petrolatum gauze packing is inserted to prevent recurrence.

A light or moderate blow on the anterior tip or the apex of the nose may produce a fracture or dislocation of the columellar portion of the septum or of the anterior nasal spine.[33] These can be reduced by digital manipulation on occasion, particularly in children, where the septum can be felt to slide into position. In adults, or in more severe childhood fractures, an Asch forceps may be needed to replace the septum in its proper position. Where there is a tendency

for the spine to remain displaced upward, creating an acute angle between the columella and lip, the spine may be anchored to the periosteum below with fine wire or catgut. Both nasal fossae should be packed to prevent hematoma, and to maintain the position of the septum.

Fractures of the upper alar cartilages and septum must be reduced to prevent hematoma and subsequent retraction due to scar formation. This is done by manipulating the alar cartilages into position, packing the nasal fossae rather firmly, and splinting externally for counter-pressure.

Other Nasal Fractures. Simple fracture of the turbinates requires no treatment. If the inferior turbinate is torn from the lateral wall of the nose, the anterior end is sutured in place whenever possible. The nose is packed to prevent adhesions with the septum or floor.

Injury to the lacrimal apparatus may result from pressure of a fractured neighboring bone. No direct treatment is necessary because reduction of the fracture will usually relieve the condition. If lacrimation continues, a subsequent dacrocystrhinostomy may be indicated.

A slight fracture through the anterior ethmoid cells may require no treatment, although the patient is cautioned against nose blowing. Fractures through the perpendicular plate are corrected by reduction of the septum. In fractures of the ethmoid, there is the possibility of a splinter from the cribriform plate, causing intracranial and olfactory damage.

The anterior wall of the frontal sinus may be fractured by a direct blow such as occurs in auto crashes. If intracranial injury can be ruled out, and there is no displacement, no special treatment is necessary. When depression is present, the fragments of the anterior plate can be elevated through a superciliary incision. The sinus is drained intranasally with a rubber tube, or externally with a rubber drain.

REDUCTION OF ZYGOMATIC AREA FRACTURES

A simple depressed fracture in the anterior portion of the zygomatic arch is readily reduced by the intra-oral approach, within three to four days after injury. A small horizontal incision is made in the buccogingival fold,[31] over the second upper molar tooth, and a heavy curved elevator is inserted under the arch, close to the periosteum. The fracture is then elevated into position. The incision is usually

Fig. 7.—Reduction of zygomatic arch fracture by Gillies approach. A and B—Characteristic depression of arch and swelling below the arch. Elevator inserted through incision in temple hairline and passed under depressed area. Pressure of elevator handle against temple raised arch into position. C and D—Appearance two weeks postoperative. Healed incision visible. Depression corrected and swelling of cheek receded. Case treated fifteen days after baseball injury. Intra-oral approach attempted earlier without success.

closed with a single silk suture. If treatment is delayed and callous formation has occurred, the intraoral approach may be ineffective, and the external temporal procedure of Gillies is used.

If the fracture is located in the middle or posterior portions of the arch, it may readily be reduced by the external temporal or Gillies[35] approach (Fig. 7). A curved incision, about two centimeters in length, is made in the hairline of the temple, and the soft

tissues are separated. The temporal facia is incised, and the temporal muscle is exposed. A curved elevator is slid downward and forward along the muscle fibers, and is inserted under the arch. Using the squamous portion of the temporal bone as a fulcrum, with a small sponge under the handle of the elevator, the fragment is lifted by pressure against the elevator handle. It readily snaps into position, restoring the arch. The incision is closed with interrupted silk sutures. An external support is usually not needed, except when there is danger that the patient might disturb the fractured area by rolling or tossing in bed. A plaster head cap,[36] or some similar device, may be of benefit when protection is necessary.

In simple depressions at the temporozygomatic suture line, it may be possible to effect reduction without incision, by use of a simple device such as a wire or fish hook.[4]

In fracture displacement of the zygoma the choice of method of reduction is influenced by the condition of the arch. When displacement of the arch is minimal, reduction may be accomplished by the inferior orbital approach. A hook, or one or both prongs of a heavy towel clip, is inserted through the skin, without incision, and is engaged over the depressed inferior orbital rim, lateral to the fracture line. The hook is then pulled forward and upward until the orbital order is restablished, and each of the four articulations are in approximation. The reduction is checked externally by palpation of the orbital border, and intraorally by palpation over the antrum wall. No fixation is required. To avoid trauma to the eyelid and eyeball, the soft tissue over the inferior orbital border is pushed above the inferior orbital border with the index finger. The hook is then insinuated under the finger, and engaged in the bony margin.

When the arch is depressed, the intra-oral approach for reduction of arch fractures is usually effective in reducing the arch and inferior orbital border. If reduction is incomplete, the hook is used as a supplementary procedure. When reduction has been postponed there beyond three to four days, the Gillies and hook techniques are used.

An external support is generally not required. To prevent dislocation during sleep, it is advisable to use a sandbag, plaster skull cap, or other protective device (Fig. 8). These devices are also valuable for use with disturbed patients.

The pathology of comminuted zygomatic fractures is similar to that of fracture displacement, but more severe. The treatment of these fractures usually requires the use of several methods of reduc-

Fig. 8.—Plaster skull cap with curved arm bumper guard. Device for protection of zygomatic area fractures following reduction.

tion in combination. For convenience, this treatment is designated as the multiple approach method. Several additional procedures have been successfully used for the reduction of comminuted fractures.

The transantral approach is an open method which is used for removing loose fragments and for raising the floor of the orbit. A buccogingival incision (Caldwell-Luc) is made, and the anterior antral wall is exposed. Loose fragments are removed from the antral cavity, and blood clots are aspirated. Overriding or depressed fragments of the walls are reduced. The depressed roof of the antrum is raised, elevating the orbital contents. To provide support, the antrum is firmly packed with a single strip of petrolatum-coated iodoform gauze. One end of the packing is protruded through the nasoantral window. The buccogingival wound is closed with interrupted sutures. Ten to fourteen days later, the packing is removed through the window. The window remains open for drainage.

The intranasal approach is used for severely depressed and impacted fragments of the antral walls. Elevation is accomplished through an inferior meatal opening made with a curved trochar and enlarged with antrum punches (Fig. 9). A heavy, curved urethral sound is introduced and pressed laterally, to relieve impacted fragments. After the sound is removed, the antrum is packed through through the window, in order to support the fragments in their reduced positions. The window remains open for drainage.

For release of impacted fragments, the intranasal approach is useful. When the orbital contents are depressed, or when loose fragments are present in the antrum, the transantral approach is valuable.

If an external laceration is present over the inferior orbital border, the rim may be approached through the wound. At times, when a

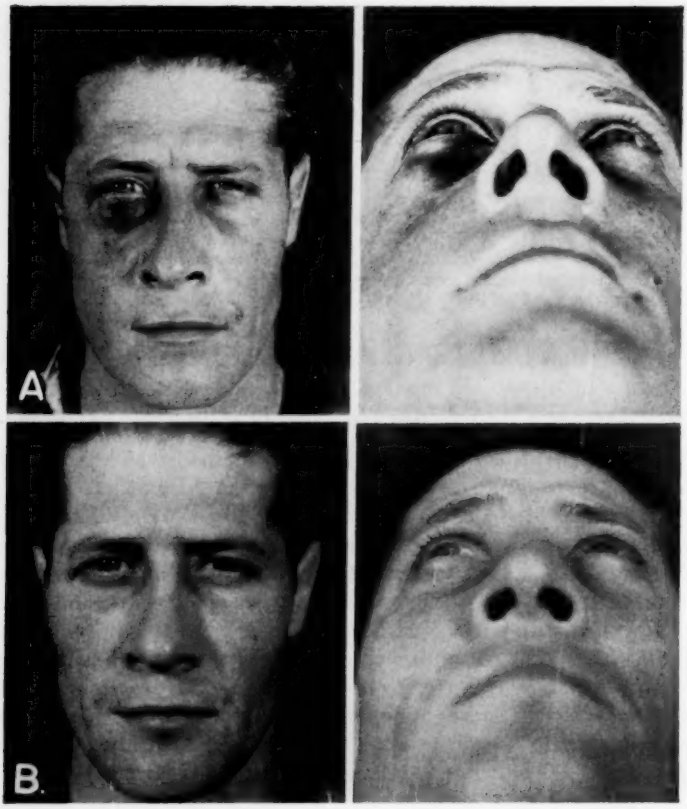

Fig. 9.—Multiple approach for reduction of comminuted zygomatic bone fracture. A. Depression over R. anterior antral wall and ecchymosis. Treated within ten days of injury. Intranasal approach reduced impacted fragments in antrum. Incision made along inferior orbital border to evacuate hematoma and to elevate inferior orbital border and zygoma. B. Postoperative view. Cheek prominence and orbital border restored. (Nasal deviation due to old injury.)

large hematoma is present in this region, it is well to make a curved incision along the border, in order to evacuate the hematoma and elevate the fragments.

Each of the approaches discussed is preferred for repairing certain fracture damage. Most zygomatic fractures have several pathological effects. Severely comminuated fractures have several types

TABLE II.

SURGICAL PROCEDURES FOR CORRECTION OF ZYGOMATIC FRACTURES.

PATHOLOGY	PROCEDURE PREFERRED
Depression of Zygomatic Arch—Anterior Portion	a. Intra-oral during first 3-4 days b. External temporal after 4 days
Depression of Zygomatic Arch—Middle or Posterior Portions	External temporal
Depression and Rotation of Zygoma	a. Intra-oral—simple and leaves no scar b. External temporal—for additional leverage c. Inferior orbital — in combined methods and for open wounds
Depression of Orbital Contents	Transantral
Fragments Within Antrum	a. Intranasal — for impacted fragments b. Transantral—for loose fragments and depressed orbital contents
Depression of Inferior Orbital Border	Inferior Orbital

of fracture damage. Therefore, reduction usually requires multiple methods. The selection of a technique in a given case depends on the particular combination of fractures. For example, depression of the inferior orbital border, occurring with impacted fragments within the antrum, can be treated by a combination of the inferior orbital approach with either the intranasal or the transantral approach.

When there has been a great deal of comminution, it may be necessary to use external fixation in order to maintain the zygoma in position. Useful methods have been devised by Straith,[30] Ivy and Curtis,[37] Erich[31] and Kazanjian.[22] Direct interosseous wiring may be used when other methods of reduction fail to maintain the position of the orbital borders. The bone is exposed in the region of the frontal or maxillary articulations, and a ligature of fine stainless steel wire is passed through drill holes to maintain the fragments in position.

NASAL INJURIES IN INFANTS AND CHILDREN

Nasal injuries are sometimes present in newborn infants. These usually occur in the region of the columellar portion of the septum, which appears displaced and carries the tip to one side. If discoloration of the mucosa is present, it may be assumed that the displacement is due to birth trauma. Where no discoloration is present, the condition may be considered developmental. In either instance, attempts should be made to reduce the columella by manual replacement to the midline. If this procedure is not successful on the first attempt, it should be repeated within several days.

Special consideration should be given to the diagnosis of nasal injuries in children because of the possibility of future deformity, both functional and cosmetic, if fractures are not recognized.[38] In children, even slight trauma may produce displacement of the septal cartilage,[33] depression or a greenstick fracture of one of the nasal bones. Cartilage is softer than bone and more easily displaced. Also, the nasal bones have not united with one another in the metopic suture line. Nearly all greenstick fractures occur in childhood. These fractures may be overlooked because the rapid swelling of the soft tissues over the nasal bridge and dorsum obscures the supporting structures. It is not wise to delay for a week or ten days until the edema recedes, because even in that short time, malunion may become fixed and correction difficult.

COMMENT

Greater participation in competitive sports, increased automobile injuries and other causes have produced an increased incidence of lesser facial fractures. The increased incidence of injuries and the improvements in diagnosis and technique of treating them, has stimulated many men to report their observations and experiences. Great emphasis is placed by most of these writers on the physiologic and cosmetic sequelae of inadequate reduction of such fractures. However, these can be largely avoided by accurate diagnosis and early treatment. Considerable time as well as mental and physical discomfort can be spared the patient if such action is taken, and meticulousness at the time of the original repair is well worth the additional effort required. Because the supporting structures of the face are located superficially, inaccuracies in reduction of these lesser facial fractures present themselves as sequqelae mentioned above, after the initial traumatic swelling subsides.

Union of fractures in both the nasal pyramid and the zygomatic areas begins rather rapidly, usually within a period of two weeks, and

is not hampered by divergent strong muscular pull, as may be found in other regions of the body. Furthermore, healing is facilitated, particularly in the pyramid area, by the layers of closely adherent mucoperiosteum and skin with their rich blood supply. The thin facial bones receive adequate nutrition as well as splinting through this factor, and a good cosmetic and functional result is promptly attained. If, however, reduction has been inadequate, and less than meticulous care has been used in the care and in the approximation of soft tissue wounds, the quick healing in these areas can produce unsightly deformities and considerable disability, which may subsequently require multiple corrective procedures.

Problems in early diagnosis are generally due to several factors. Rapid edema or hematomas which occur after trauma to the soft tissues of the face, obscure bony deformities. Other more obvious or serious trauma may divert attention from the lesser facial injuries. In children, at the time of injury, little or no deformity may be noted, and medical attention is not sought. However, these slight injuries may later produce considerable disability. Roentgenography, while of great help in most cases, fails to be of value in certain ones. If more attention were paid to cases of suspected lesser facial fractures at the time of the accident, and if all diagnostic methods were used, adequate early treatment could be effectively administered.

Various techniques have been used for the reduction of fractures in the nasal pyramid area, as well as in the zygomatic. In some cases, no single method is adequate for good reduction, and a combination of methods or multiple techniques may be required for satisfactory reduction. In the pyramid area, for example, overriding fragments would require elevation before underriding fragments could be lifted into position. Attention to the septum might be required simultaneously. In fractures of the zygomatic area, impaction of bony fragments within the antrum might require dis-impaction by one method, before elevation by another method would succeed.

Both open and closed methods of treatment are available for these fractures. In the treatment of fractures of the pyramid, some workers feel that open reduction, using the intranasal rhinoplastic approach, is superior because hematoma can be quickly evacuated and bony fragments approximated by direct vision. Most surgeons, however, continue to prefer the more conservative closed methods, which are simpler, quicker, and require less instrumentation. Closed reduction also permits primary modeling for good gross contours; if results are not satisfactory, a better re-alignment can be attempted

within a few days. Closed reduction without consideration of the position of the fragments will give poor results. Therefore, in preparing for closed procedures, the position of the fragments must be visualized and the proposed method of reduction adequately planned. Many surgeons use a combination of both open and closed methods, reserving the open methods for cases of severe comminution or impaction, where manipulation by closed methods is unfeasible.

SUMMARY

1. This paper is concerned with mild and moderately severe fractures of the nasal pyramid and zygomatic areas, which are described as lesser facial fractures.

2. These fractures are significant because of the functional and cosmetic sequelae which may occur if reduction is inadequate. Functional sequelae include disturbances of the respiratory, olfactory, visual, masticatory, neurological and psychological systems. Cosmetic sequelae include nasal, ocular and facial asymmetry, as well as ugly scar formation of the soft tissues.

3. Detailed procedures for diagnostic examinations of facial fractures are presented. These include history, inspection, palpation and roentgen studies. A table is included presenting the diagnostic value of various roentgen views. The diagnostic criteria for specific fractures in the nasal pyramid and zygomatic areas are presented. Since multiple fractures are involved, the relative position of the fragments must be understood to obtain accurate approximation.

4. In the repair of soft tissues, particular attention must be paid to the closure of the folds and orifices of the face. Ugly scar formation and notch deformities of the nares are minimized by meticulous care in wound closure.

5. Treatment of nasal pyramid area fractures is described. The first step in the treatment of external deviations and depressed frontal fractures is the release of impaction. The septum is then repaired, and the nasal bones and frontal processes are reduced. The treatment of other fractures of the pyramid is summarized.

6. The principal zygomatic area fractures discussed are the zygomatic arch fractures, fracture displacement of the zygoma, and comminuted zygomatic bone fractures. Five valuable approaches for reduction of these fractures are the intra-oral, the external temporal, the inferior orbital, the transantral, and the intranasal. Each is preferred for certain phases of treatment. In many instances, multiple approaches are necessary for satisfactory results.

7. Nasal fractures and septal dislocations in children are often overlooked. While many of these fractures may appear trivial, septal and external deviations may become progressively more noticeable with development.

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Clinical Notes

XC

GRANULAR CELL MYOBLASTOMA OF THE VOCAL CORD

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In 1926 Abrikossoff[1] first described an unusual tumor which he called "myoblastenmyome" and presented five cases. Later he reported[2] another, a pea-sized nodule occurring on a vocal cord. The tumor is referred to in the English literature as "granular-cell myoblastoma," and numerous examples have now been reported. These tumors most commonly occur in the tongue and the subcutaneous tissues. Until recently, the theory that they were of striated-muscle origin was accepted, but Fust and Custer[3, 4] have presented evidence that they may possibly be of nerve origin. Ten cases of this tumor which have arisen in the vocal cords have been reported previously. The present case is a typical example of a benign granular cell myoblastoma of the vocal cord.

REPORT OF A CASE

R. T., age 33, colored male, was seen in the Department of Otolaryngology because of frontal headaches. He gave no history of hoarseness or dysphagia. Examinations of the ear, nose, and throat were negative. Mirror examination of the larynx revealed a whitish, somewhat glistening nodule 0.3 x 0.3 x 0.4 cm on the left cord at the vocal process. No inflammation or infiltration was present, and the cords and arytenoids moved normally on phonation. By direct laryngoscopy under topical anesthesia, the lesion was removed with biting cup forceps. Four months later, recheck of the larynx showed no evidence of recurrence.

From the Surgical (ENT) and Laboratory Services, Veterans Administration Medical Teaching Group Hospital, Memphis 15, Tennessee.

Fig. 1.—Photomicrograph showing large cell with granular cycoplasm and small nuclei.

Fig. 2.—Photomicrograph showing flattened squamous epithelial lining and a focus of pseudoepitheliomatous hyperplasia within the tumor.

Microscopic Appearance: The specimen was firm, grayish white, and smooth on one surface. The epithelium was markedly thinned, and the tissue beneath was filled with closely-packed, medium-sized cells having a granular, pale-staining cycoplasm and small deep staining ovoid nuclei (Fig. 1). There was no definite cell pattern. In several places just beneath the thinned squamous epithelium were epitheliomatous pearls, probably representing remnants of pseudoepitheliomatous hyperplasia (Fig. 2). There was no evidence of malignancy in the sections. The cytoplasm of the cells did not show fat with Sudan IV stains and did not stain by the periodic acid Schiff method.

These lesions occur most frequently in the fourth decade, affecting both sexes equally. The principal symptom recorded is hoarseness. The tumors arising on the cords are usually small. A few have been lobulated, but all have been well circumscribed and benign. The color is gray white, pink, or slightly yellow. They grow slowly. Proliferation of the epithelium overlying these tumors has been noted many times, and should not be confused with squamous cell carcinoma.

As mentioned earlier, these tumors are usually found in the tongue and subcutaneous tissues, but also occur in many other regions. Howe and Warren[5] and Ravage et al[6] have described malignant degeneration in these lesions, and the percentage of malignancy has been estimated at one to two per cent.

The exact origin of these tumors is in doubt. Murray,[7] felt that the cultural characteristics of these tumors indicated probable muscle origin. Fust and Custer[3, 4] found many of them associated with nerves, and frequently groups of tumor cells were observed within the sheaths of nerves. Their view that they are of nerve origin has been supported by the investigations of Ashburn and Roger[8] and Bangle.[9, 10] Pearse[11] believes that they originate from fibroblasts. The theory that they arise from histiocytes (storage-cells) is not supported by histochemical and polarization studies.

The treatment is surgical excision with adequate margin. In one case in which the tumor arose in the tongue[12] deep roentgen therapy produced no significant change. While more than 200 have been reported, only eleven, including the present one, have arisen in the vocal cords, and these have been benign.

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XCI

MYXOLIPOMA OF THE BASE OF THE TONGUE

REPORT OF A CASE

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Myxomas and mixed connective tissue tumors containing myxomatous material are so infrequently encountered in any location in the body that the finding of such a tumor would justify its presentation. The case presented here is unique in its clinical symptoms, pathological findings and location, the site being that of tumors which are predominantly malignant.

A rather exhaustive search of the literature fails to reveal any prior cases of myxolipoma, myxoma or other similar tumor on the base of the tongue. Babbitt and Pfeiffer[1] report a pure myxoma of the palate and pharynx and found in the literature no more than six other pure myxomas of the pharynx. Their terminology of "myxoma did not preclude the occasional admixture of fibrous, cartilaginous and other combination types." Tholen[2] has reported a case of myxoma of the tonsil, soft palate and lateral pharyngeal wall. MacCready[3] described a myxoma of the pharyngeal wall, lateral to the right tonsil. Novelli[4] described a myxoma of the larynx arising from the left false cord, requiring tracheotomy and laryngofissure for removal. Colbert[5] described his treatment of myxoma of the vocal cords. However, in his case, no tissue was removed for pathologic study. Urfer[6] reported one case of myxolipoma of the larynx, attached to the aryepiglottic fold, and showing sarcomatous changes.

Myxomas and other benign tumors of the pharynx are reviewed in the paper by Babbitt and Pfeiffer.[1] New and Erich[7] have written

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on benign tumors of the larynx, reporting three cases of myxoma. We have, however, found no reference to myxolipoma or myxoma on the base of the tongue and the following case is therefore presented.

The patient, a 52 year old white male, was admitted to the Otorhinolaryngology Service of the North Carolina Baptist Hospital on March 4, 1953. He was first seen in the Department of Medicine, having been referred for investigation of his complaint of being unable to swallow. He had noted progressive difficulty in swallowing for approximately three months, during which time he had lost 30 lbs. in weight. He had had no cough, nausea, vomiting, abnormal bleeding or pain. He stated that the difficulty in swallowing was due to a "growth in his neck," seemingly more on the left side.

Past history and family history were not contributory to the present illness.

The patient was a thin, well developed, elderly white male. His blood pressure was 160/80, pulse 65. The pertinent physical findings were limited to the base of the tongue and pharynx. By depressing the tongue, or by having the patient protrude the tongue and phonate, a large, smooth, glistening, pink, rounded mass appeared in the pharynx. There appeared to be some motion of this mass; that is, it was not densely adherent to the tongue. Examination with the laryngeal mirror showed the mass to occupy the entire vallecular area, the epiglottis being noted only on the right side and only its superior border being seen. No pedicle could be seen.

Laboratory findings showed: urine, clear, sp. gr. 1.005, negative for albumin and sugar and no cellular elements were seen microscopically. Examination of the blood showed: hemoglobin 12.5 gms. per 100 cc, RBC 4,400,000, WBC 6,400, PMN 51 per cent, nonsegmented PMN 2 per cent, eosinophiles 1 per cent, lymphocytes 45 per cent, monocytes 1 per cent. Blood Kahn and Wasserman reactions were negative.

Direct laryngoscopy showed that the mass was attached to the base of the tongue; there was no pedicle. On March 6, 1953, under intravenous sodium pentothal and d-tubo curarine anesthesia the mass was removed. An endotracheal tube was placed with difficulty. A heavy silk suture was placed through the tongue at the junction of the anterior and middle thirds and was used for traction. This brought the mass into view and on exploration with the index finger it was thought that the epiglottis could be identified and was possibly involved in the tumor. A suture of No. 2 chromic catgut was

Fig. 1.—Cut surface of the tumor, showing lobulation.

placed in the base of the tongue, at the attachment of the mass, to be used for traction and hemostasis if necessary. Because of the cystic appearance and feel, a needle was introduced and an attempt was made to aspirate the mass. No fluid was obtained. An incision was made through the mucosa at the base of the mass and a cleavage plane was entered immediately. By blunt dissection the entire mass shelled out easily. Bleeding was minimal. Excess mucous membrane of the area was removed. A small, separate firm mass which projected to the left, attached to the mucosa covering the large mass, was removed. There was no erosion or deficiency of the epiglottis. The black silk traction suture through the tongue was left in place for six hours as a safety measure. The patient was discharged from the hospital on the second postoperative day; he took a soft diet without difficulty.

He has been seen on several occasions since. The operative area has healed cleanly without evidence of recurrence of a tumor mass. He was taking a full diet and had gained 14 pounds in eight weeks.

The gross specimen consisted of an encapsulated, lobulated, soft mass which measured 4.5 x 3.7 x 2.0 cm. The external appearance

was smooth, glistening and pinkish gray. Numerous small blood vessels traversed the surface of the tumor. On cut section the tissue was gray, slick and somewhat laminated. Two other pieces of similar tissue were presented which measured 1.0 and 1.2 cm in greatest dimension.

Histologically all sections of the tumor had a similar structure. The surface was covered by a thin collagenic tissue capsule which connected with numerous interlacing trabeculae, the latter dividing the tumor into many lobules. The neoplasm consisted of approximately 60 per cent myxomatous connective tissue and 40 per cent adipose tissue. The myxomatous areas were composed of uniform spindle and stellate shaped cells situated in a pale edematous matrix. The fat cells consisted of large pale spaces (lipid cytoplasm removed by organic solvents) with small flattened peripheral nuclei. In all sections, both the myxomatous and adipose tissue showed uniformity in size and staining characteristics of the cells. No mitoses or giant cells were seen. There was no demonstrable invasion of endothelial-lined spaces or extension into surrounding tissue. Scattered throughout the tumor were capillaries surrounded by small foci of lymphocytes and plasmacytes. A portion of the specimen was covered by squamous mucosa containing collections of mucous glands of minor salivary type. After staining the section for reticulin, a delicate network of deeply basophilic to black fibers was found throughout. The myxomatous areas were slightly pink following mucin stains despite fixation in formalin and not the preferred Zenker's solution. This was interpreted as being faintly positive. No fat stains were performed.

The diagnosis was myxolipoma of the base of the tongue.

COMMENT

In the opinion of Stout,[8] the presence of immature fat cells (lipoblasts) would automatically rule out the diagnosis of pure myxoma. According to Ward and Hendrick,[9] islands of embryonic fat indicate the malignant nature of change of these tumors, unless these have been brought about by injudicious irradiation therapy. However, this tumor is considered to be a benign neoplasm of embryonic connective tissue or mesenchyme which is differentiating in both myxomatous and lipomatous directions. This lesion rarely, if ever, metastasizes, but does infiltrate or dissect locally quite extensively. Therefore, the usual treatment is wide local excision. If a malignant change occurs in this tumor, it is indicated by an increased cellularity and the presence of numerous mitoses.

SUMMARY

Although myxomas and myxolipomas have been found in the pharynx, larynx, soft palate and tonsil, none has been reported on the base of the tongue. The clinical, surgical and pathological findings of a myxolipoma in this location are presented.

BOWMAN GRAY SCHOOL OF MEDICINE.

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XCII

THE GLOMUS JUGULARE, A NONCHROMAFFIN PARAGANGLION, IN MAN

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At the meeting of the American Association of Anatomists held in Chicago in April, 1941, I reported the presence of previously unrecognized structures in human temporal-bone sections. Because the structures are small (usually less than half a millimeter in the longer dimension) and are located near or in the wall of the jugular bulb more often than elsewhere (Fig. 1), the name of "glomus jugularis," or jugular body, was proposed as appropriately descriptive.

In the brief abstract of the report, published in the program of the meeting in the Anatomical Record,[4] it was pointed out that, so far as can be judged from sections 24 microns thick made from decalcified material and stained only with Ehrlich's hematoxylin and eosin, the jugular body is histologically like the carotid body, being composed essentially of blood vessels of capillary or of pre-capillary caliber with numerous epithelioid cells between the vessels (Figs. 2, 3 and 4).

The abstract of my report came to the attention of Dr. Harry Rosenwasser while he was studying sections of a tumor in the middle ear of a patient on whom he had operated. After correspondence with me, he suggested in his report[10] of the case that the tumor may have arisen from a glomus jugularis instead of from the carotid body,

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which it resembled histologically. Since Rosenwasser's paper appeared, reports have been made of more than 45 tumors, each of which may have arisen by an abnormal growth of a jugular body. The clinical and pathological features of such tumors have been well stated in several of the reports; the papers by Winship, Klopp and Jenkins,[14] Bartels,[1] Lundgren,[9] Lattes and Waltner[8] and Berg[2] are particularly recommended to those who are interested in this aspect of the topic. References to the other reports of glomus tumors of the middle-ear region may be found in these papers. The present paper will be limited, for the most part, to a consideration of the normal jugular body in man, on which aspect of the topic no reports other than my brief abstract appear to have been made, in spite of the interest stirred up by the reports of tumors.

COMMENTS ON TERMINOLOGY

Both Lundgren and Berg, in their reports of the material at Lund, propose the name "tympanic gland" or "tympanic body" for the structures termed "glomus jugularis" by me. Their proposal is based on the idea that the structures described by Valentin,[11] in 1840, and by Krause,[6] in 1878, were like those to which I called attention in 1941. Lattes and Waltner and Lattes[7] have also expressed the idea that Krause and Valentin preceded me in observation of the structure termed glomus jugularis, but these writers did not propose a return to the earlier terminology. If I agreed with their impressions I would gladly concur, on historical grounds, with the terminology suggested by the Swedish authors. Actual perusal of the papers by Valentin and by Krause, however, convinces me, and will, I believe, convince anyone who is familiar with the histologic appearance of the glomus jugularis, that the earlier descriptions were not based on observations of this structure.

Small aggregations of peripheral, or so-called aberrant, ganglion cells are of common occurrence along the course of the nerve of Jacobson (the tympanic branch of the glossopharyngeal nerve); they have been described or mentioned by numerous writers. Valentin's account is clearly nothing but a description of such a structure, and was so recognized by Krause (Handbuch, Bd. 3, S. 200). Krause's[5] own account, in the paper entitled "Die Glandula tympanica des Menschen" and in the corresponding section of his Handbuch (Bd. 2, S. 860-861 and Fig. 521), concerns only the connective tissue in the osseous canal (canaliculus tympanica) through which the nerve

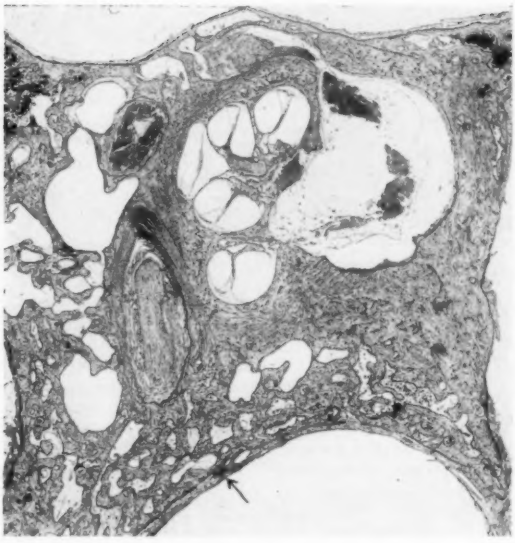

Fig. 1.—Photomicrograph, at a very low magnification, of a "vertical" section of a human temporal bone, to show the location, and relationships to other structures of the ear, of a typical glomus jugulare (indicated by the arrow). This jugular body is of the size termed "medium" in the text (about 0.5 mm in longest dimension); it is in the adventitia of the dome of the jugular bulb and is near the portion of the nerve of Jacobson between the origin of this branch of the glossopharyngeal nerve (anterior to the plane of this section) and its entrance into the jugular fossa end of the tympanic canaliculus (posterior to the plane of this section). The histologic appearance of this glomus is shown in Figure 2.

of Jacobson, the tympanic branch of the ascending pharyngeal artery and the accompanying vein or veins pass from the jugular fossa to the middle-ear cavity. The connective tissue in this osseous canal is continuous with the outer layer of the adventitia of the jugular bulb, and the contained cellular elements are of the usual connective-tissue types; it is therefore surprising to me that so good an anatomist as was W. Krause should have regarded this tissue as an organ. The structure I termed the glomus jugularis does occur, and indeed rather often (see below), in the canaliculus tympanica, but there is no evidence, either in his text matter or in his drawing, that the specimens Krause examined contained such a structure.

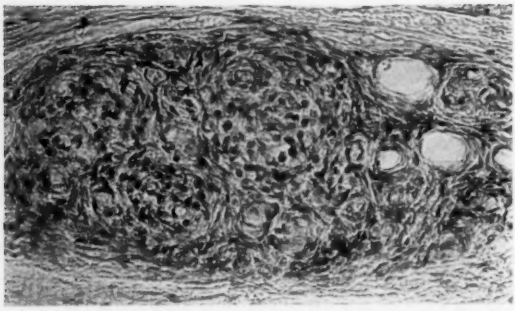

Fig. 2.—Photomicrograph, at a moderately high magnification, to show the histologic appearance of the typical glomus jugulare whose location is shown in Figure 1. The proportion of epithelioid cells to blood vessels is in this glomus about average for the material. Compare with Figures 3 and 4, which are at the same magnification, for the range of variation observed in histologic appearance of the normal glomus jugulare.

From what has been said above, it is obvious that I agree with the conclusion reached by Watzka,[12] in 1932, as a result of his study to determine anew the true histologic basis for the continued mention of glandula tympanica, or of the synonyms for it, in handbooks of anatomy. If, however, Watzka had examined material from a larger series of cases, had used serial sections of the region and had examined the tissue in the jugular fossa, he doubtless would have discovered the glomus jugularis himself and would not have had to arrive at the entirely negative conclusion he did, namely, that neither of the things seen by Valentin or by Krause should be called a gland.

With the correction of my spelling by Lattes and Waltner[8] I can only concur; authorities agree that the proper Latin ending of "jugulum" as an adjectival modifier of "glomus" is "are," not "aris." I should not have trusted my memory of Latin forms. Fortunately the mistake will not cause ambiguity in the literature on the topic or difficulty in the finding of references in indexes.

Several small structures that closely resemble the carotid body histologically have been described and recorded in the literature, each under a name or names indicative of anatomic location rather than of morphology. These structures include the carotid body itself,

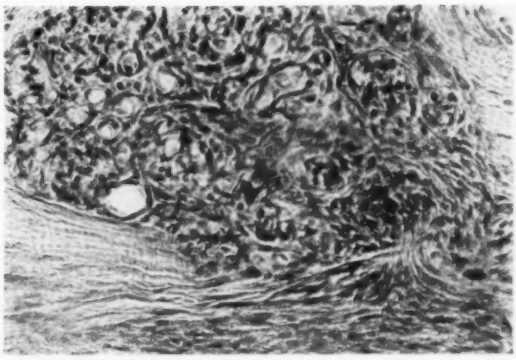

Fig. 3.—Photomicrograph, at the same magnification as Figure 2, to show the histologic appearance of a normal glomus jugulare in which the proportion of vascular elements to epithelioid cells is high. Compare with Figures 2 and 4. In this photograph, toward the lower right, may be seen the entrance into the glomus of a considerable number of nerve fibers; they come from the adjacent nerve of Jacobson which is only partially included in the picture (at the lower edge).

the aortic bodies, the supracardial aortic paraganglion, the intravagal and juxtavagal paraganglia, the ciliary paraganglion in the orbit, and the glomus jugulare in its various locations near or in the middle ear (see below). References to literature about some of these structures may be found in the recent paper by Lattes.[7] This author urges that a collective, or generic, term is needed for this group, or system, of organs, and he proposes that Watzka's suggestion, in 1943, of "nonchromaffin paraganglia" be adopted for the normal structures and that tumors arising from any member of this system of organs be termed "nonchromaffin paragangliomas." The proposed terminology is a logical one, on the basis of what is yet known about the several members of the group of structures, and its use should reduce the confusion presently existing in this field of study, particularly with respect to the indexing and to the finding of pertinent literature. It is therefore to be hoped that use of the collective terms proposed by Lattes will be widely adopted.

MATERIAL AND OBSERVATIONS

Of the laboratory's collection of human temporal-bone sections, prepared for other purposes, 88 series (both ears of 44 persons) have

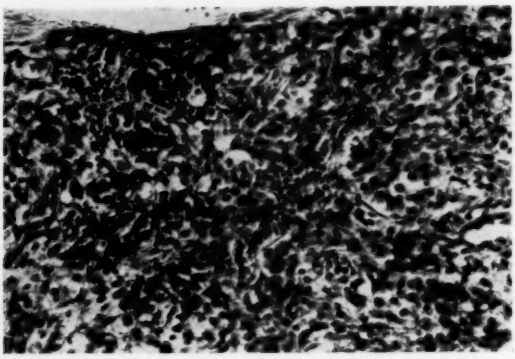

Fig. 4.—Photomicrograph, at the same magnification as Figure 2, to show the histologic appearance of a normal glomus jugulare in which there is a high proportion of epithelioid cells. Compare with Figures 2 and 3.

been examined for the presence of glomus formations. The technique of preparation of the temporal bones for histologic study is given in the paper on the pathology of high-tone deafness;[3] in brief, it consisted of formalin fixation, decalcification in 1 per cent nitric acid in 10 per cent formalin, deacidification in 5 per cent sodium sulphate solution, thorough washing in water, dehydration in ascending strengths of ethyl alcohol, celloidin infiltration and embedding, serial sectioning at 24 microns in the so-called vertical plane, staining of each tenth section with Ehrlich's hematoxylin and eosin, mounting in gum damar dissolved in xylol. In a few instances, each fifth section, through part of the series, has been stained and mounted. Material thus prepared is not suited to the determination of the finer details of cellular structure, and thus far it has been impracticable to isolate jugular bodies at the autopsy table and prepare them by special cytologic methods. My study of the material has therefore been primarily with respect to the locations in which glomus formations occur, the frequency of their occurrence in the several anatomic locations, the variations in total incidence of glomera in ears, and the distribution of these variations with respect to side of head, age, race and sex. The latter item is of special interest with respect to glomus tumors of the ear region, because a high proportion of the reported tumors have been in women.

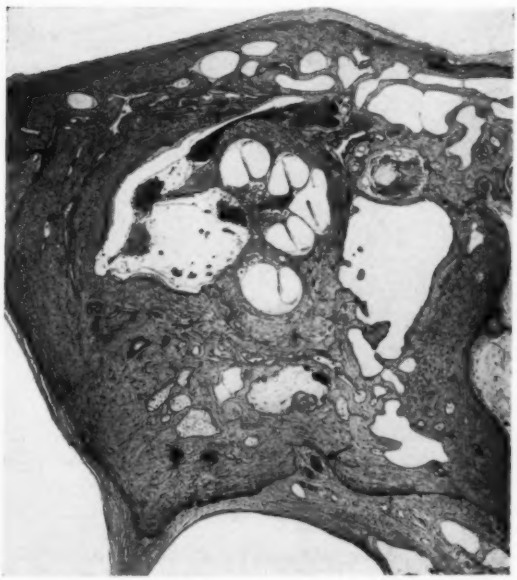

Fig. 5.—Photomicrograph, at a very low magnification, of a "vertical" section of a human temporal bone, to show the location and relations of a glomus jugulare (indicated by arrow) along the course of the nerve of Jacobson in the jugular fossa end of the tympanic canaliculus. The external form of this glomus, as may be better seen in Figure 6, is irregular; its shape is determined largely by its location between two locally somewhat separated fasciculi of the nerve of Jacobson. In this ear, the nerve of Arnold (slightly downward and to the left) is much closer to the nerve of Jacobson than usual for this part of the jugular fossa. The three tiny nerves below the nerve of Arnold are anastomotic branches from the glossopharyngeal; they join the nerve of Arnold posterior to the plane of this section.

The glomus formations observed in the early part of this study, previous to the report in 1941, were in all instances along the course of the nerve of Jacobson (the tympanic branch of the glossopharyngeal nerve), either in its course through the adventitia of the anterior part of the dome of the jugular bulb, or in the osseous canal (canaliculus tympanica) that transmits it from the jugular fossa to the middle-ear cavity (Figs. 5 and 6), or along the course of the nerve over the promontory of the cochlea (Figs. 7 and 8). Soon after this

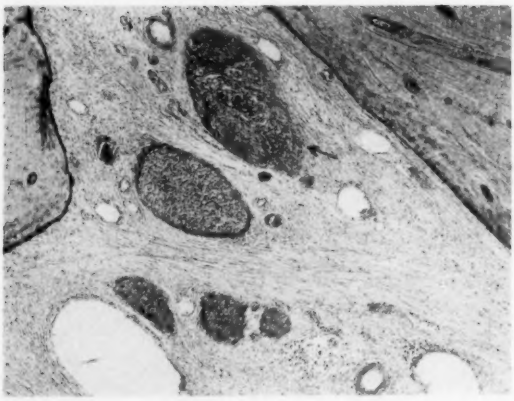

Fig. 6.—Photomicrograph, at a higher magnification than in Figure 5, of the normal glomus jugulare and nearby structures present in that section; for identification of items see the legend of Figure 5.

report was made, the fact was recognized that structures identical histologically with those observed along the course of Jacobson's nerve also occur along the course of the nerve of Arnold (the auricular branch of the vagus nerve). Why these glomera were at first overlooked I do not know, neither do I know why the glomus formations in the region of the ear were not noticed and recorded many decades ago, by previous generations of students of temporal-bone sections. Examples are not especially difficult to find when they are deliberately sought.

In the 88 ears that constitute the material of the present report, 248 glomus formations have been found; 135 of them are closely associated with the tympanic branch of the glossopharyngeal nerve and 113 of them with the auricular branch of the vagus nerve. The distribution of the observed glomera along the courses of the respective nerves will be stated later in this account.

The average number of glomus formations per ear is, on the basis of the present material, 2.82. Two facts make it probable that this figure is somewhat lower than the actual number present: (a) some glomera are so small that they might, by chance, lie entirely

Fig. 7.—Photomicrograph, at a very low magnification, of part of a section of a human temporal bone that has a glomus jugulare (indicated by the arrow) in the mucosa over the cochlear promontory, along the course of the tympanic plexus portion of the nerve of Jacobson. Note also that the nerve of Jacobson, because of its irregular course in this specimen, is included at three places in the section: (1) in the upper end of the tympanic canaliculus (toward lower left part of the photomicrograph), (2) about the middle of the promontory, near the basal turn of the cochlea, and (3) in its osseous canal beneath the cochleariformis process and the tendon of the tensor tympani muscle (upper left part of the picture). In other specimens a glomus formation has been found at each of these locations along the nerve of Jacobson.

in those sections intermediate between the ones (each tenth of each series) that have been stained, mounted and examined; and (b) in many of the series of sections examined, portions of the jugular fossa region are missing, due to differences in the size and height of this variable structure and to differences in the trimming of the inferior surfaces of the temporal-bone blocks during histologic preparation. With respect to the amount of the jugular fossa that is included in the sections made, the material has been grouped on the basis of estimates, in general terms, as follows: Most, 46 ears; Much, 21 ears;

Little, 12 ears; Very Little, 1 ear; None, 5 ears; Soft Tissues Torn Out, 3 ears. One or more glomus formations are present in 78 of the 88 ears.

Of the ten ears in which no glomus was found, six are among the cases not really satisfactory for inclusion in this study, either because none of the jugular bulb was present in the block sectioned (two cases) or because only a little of the bulb was present (two cases) or because very little of the bulb was present (one case) or because the soft tissues had been torn out of the jugular fossa (one case). The conclusion would therefore not be warranted that these six ears actually did not have glomus formations. But for four of the ten ears in which no glomus was found, the amount of the jugular bulb present in the sectioned block was rated as "Most," so that a glomus actually present but not found would have to be so small as to lie entirely in the sections between the ones stained and mounted for examination. Although the above stated possibility cannot at present be excluded as the explanation for the absence of a glomus in these four specimens, it seems probable, especially in view of the inconstant occurrence of glomera in each of the regions in which they have been observed in other specimens (see below), that occasionally no glomus formation is present in an ear. The incidence of the absence of a glomus, on the basis of the present observations (4 out of 82 ears) does not exceed 5 per cent.

The number of glomera in an ear, on the basis of the material examined, differs from possibly none (see above) to as many as twelve. Seven of the 88 ears have more than six glomera each. Sixty of the 88 ears have either one, two, three or four glomera each.

A marked tendency to bilateral similarity in the number of glomus formations is apparent in the material. Fourteen of the 44 persons whose ears have been examined for the presence of glomus formations have the same number in each ear, 16 have a difference of only one in the numbers present, six have a difference of two, and only eight persons have a difference of three or more in the numbers of glomera present in the right and in the left ears. Nine glomera were found in the left ear of the person, a 35-year-old white woman, whose right ear had the largest number, 12, that have been found in the sections of one temporal bone.

Grouping of the material on the basis of race and sex shows that neither of these items is significantly related to the number of glomus

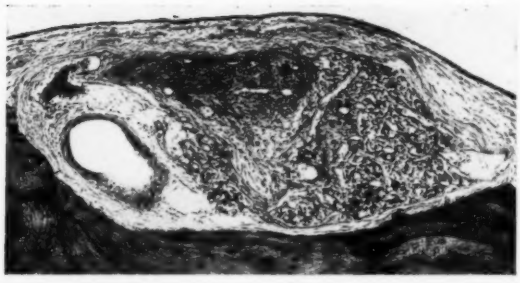

Fig. 8.—Photomicrograph, at a medium magnification, of the glomus jugulare whose location is shown in the preceding illustration. Note the lobulation of this glomus and its rich vascularity. The small artery nearby is the tympanic branch of the ascending pharyngeal.

formations in the temporal-bone region. For the white males (17 persons) and for the white females (12 persons) the average number of glomera is exactly the same, 2.8 per ear; the negro males of the material (nine persons) have an average of three glomera per ear, the negro females (6 persons) have an average of 2.7 glomera per ear. In these groupings the factor of age (see below) is well excluded: the average of the ages of the persons in the two groups of males are 46 and 48 years, respectively; for each of the two groups of females the average of the ages is 37 years.

Side of the head, likewise, is not significantly related to the number of glomus formations in the ear region; 119 of the glomera found are in right ears, 129 are in left ears. For the group of negro males (see above) the total number of glomera in right and in left ears is exactly the same; for the group of negro females there are two more glomera in the right than in the left ears; for the group of white females there are three more glomera in the left than in the right ears; and only for the group of 17 white males is there a difference that, if also present in the other groups, might possibly be regarded as significant, namely, a total of nine more glomera in the left ears than in the right ears.

The factor of age, in contrast to those of race, sex or side of head, does appear to be significantly related to the number of glomus formations present in the region of the ear. In the material studied,

TABLE. 1.—INCIDENCE OF GLOMUS JUGULARE, BY AGE-GROUPS.

AGE IN YEARS	NUMBER OF PERSONS IN GROUP	AVERAGE NUMBER GLOMERA PER EAR
Under 20*	6	2.0
20 - 29	7	2.7
30 - 39	6	4.6
40 - 49	9	3.6
50 - 59	5	3.7
60 - 69	7	1.8
70 - 79	4	0.6

*The youngest two were 8 and 12, the others 16 to 19 years of age.

the average number of glomera present is largest in the period of mid-adult life. The numerical data on this point are given in Table 1. For the combined group of persons aged 30 to 59 years, the average number of glomera per ear is 3.9. The peak shown for the group 30-39 years of age is probably not significant, because the omission of one case, that of the person with the largest number of glomera found in the material (see above), would reduce the average number for this group to 3.4 glomera per ear, a figure that is close to those for the two next older age-groups of the tabulation. Support is afforded the idea that more glomera are normally present during the period of mid-adult life than at other times by two facts other than the averages given in Table 1: (a) all but one of the seven ears with more than six glomera each (see above) are from persons between the ages of 30 and 59 years, and (b) none of the ten ears in which no glomera were found, whatever the cause (see above), is from a person of this age-group.

The tabulation shows a marked decrease in the average number of glomera per ear present after the age of 60 years; for the group

Fig. 9.—Photomicrograph, at a very low magnification, of a "vertical" section of a human temporal bone, to show the location, and relations to other structures of the ear, of a normal glomus jugulare (indicated by the arrow) along the course of the nerve of Arnold in the adventitia of the lateral part of the dome of the jugular bulb. Note the position of the glomus with respect to the tympanic membrane.

60 to 69 years old the figure is about half of that for the preceding decade group, and for the small group of persons 70 to 79 years of age the average number of glomera found is less than one-sixth of the number found in the ears from persons of the mid-adult age period. To explain the decrease on any basis other than that it actually occurs is difficult, especially in view of the fact that for only 5 of the 22 blocks, of the ears from persons 60 years of age and older,

was the amount of the jugular fossa present estimated, from the sections, as other than "Most" or "Much" (see above).

An increase in the average number of glomera per ear during adolescence and early adult life is indicated by the data recorded in Table 1. For the yet younger age-groups similar data have not yet been obtained; the material examined thus far has been selected entirely from the collection of cases for which records of hearing acuity during life are available. If, when obtained, the data about glomera in young children, including a group of newborns, do follow the trend indicated by the figures in Table 1, the conclusion will be inescapable that many of the glomus formations in the ear region in adults are transient structures, developing during childhood, adolescence and early adult life and disappearing after mid-adult life.

Support would be afforded the foregoing tentative conclusion if the more numerous glomus formations of the mid-adult age-group of the material were also, on the average, larger in size than they are in the younger and in the older age-groups. Such support is, however, not definitely afforded by the present observations.

In size, the glomus formations of the material differ considerably, from ones about 1.5 mm long to ones about 0.1 mm in diameter. The majority of them are less than 0.5 mm in the longest dimension. The shape of most of the glomera appears, from the sectioned appearrance, to have been a flattened ovoid; some were definitely irregular in external conformation, either lobulated or molded by the pressures of adjacent structures.

With respect to relative sizes, the 248 glomus formations of the material have been divided into five categories, as follows: Very Large (10), Large (33), Medium (53), Small (91), Tiny (61). Classification has been based on impressions gained during inspection with a microscope, not on actual measurements of the sectioned glomera. The ones classified as of medium size are, if of regular shape, about 0.5 mm long and about 0.25 mm thick. If all the sections, instead of only each tenth section, had been stained and mounted for study, measurements of the dimensions of each glomus would have been made and utilized for the grouping into sizes. The use of each tenth section of a series, however, introduces possible errors into measurements of objects the size of the glomus jugulare, errors of such magnitude that the reliability of grouping on this basis would be at least

TABLE 2.—INCIDENCES OF VARIOUS SIZES OF GLOMUS JUGULARE IN DIFFERENT AGE-GROUPS OF THE MATERIAL.

AGE IN YEARS	NUMBER OF PERSONS IN GROUP	PER CENT OF GLOMERA OF SIZE		
		LARGE OR VERY LARGE	MEDIUM	SMALL OR TINY
Under 30	13	13	16	71
30 - 59	20	19	24	57
60 - 79	11	20	17	63
All Ages	44	17	21	62

as low as it is by the method of estimation used. In any reclassification of the same specimens, by myself or by another examiner, some of the glomera would doubtless be assigned differently than has been done in the present study.

The distribution of glomera with respect to size shows only a tendency, probably not statistically significant, for size to be related to age. A summary of the data with respect to this relationship is given in Table 2. In this tabulation, the categories of "Very Large" and of "Large" have been combined, likewise the categories of "Small" and of "Tiny," for reasons that are stated in the preceding paragraph. Tabulation with respect to all five categories of size and to decades of age reveals no more of a tendency to a relationship between size of glomus and age than does the summary presented in Table 2.

The histologic structure of the glomus jugulare, so far as it has been determined, is like that of the carotid body (glomus caroticum). The method of preparation used for the temporal-bone material, as has been noted above, imposes severe limitations on the study of cytologic details of the glomus jugulare. Successful isolation of this organ in the fresh condition followed by the use of special cytologic techniques may eventually reveal essential morphologic differences between it and the carotid body. As yet, however, no characteristic has been found by which, under the microscope, a section of one of these structures can be distinguished from a section of the other, when gross size and anatomic relations are disregarded.

Each glomus jugulare appears, in sections stained with hematoxylin and eosin, to consist essentially of small blood vessels, capillary or pre-capillary in size, and of epithelioid cells in the spaces between the blood vessels. Most of the blood vessels seen in section give the impression that they are pieces from coils or loops; only the venules give the impression of being from fairly straight vessels. Each glomus has a thin capsular layer of fibrous tissue, which in the larger glomera is continuous with fibrous septa between the small lobulations. Whether or not the epithelioid cells themselves are surrounded, separated and supported by continuations of the fibrous capsule or by a reticular type of connective tissue cannot be determined satisfactorily from the present material. Reticular tissue has been reported around the epithelioid cells of tumors of the glomus jugulare; the same type of connective tissue probably is present in the normal organ.

Jugular bodies differ with respect to the proportion of epithelioid cells to blood vessels; the cellular elements dominate the histologic appearance of the sections of some glomera, while in others the blood vessels constitute the more prominent feature (Figs. 3 and 4). Usually all the glomus formations of an ear have a similar histologic appearance. In several instances, however, the two ears of a person have glomera that differ markedly from each other with respect to the proportions of the cellular to the vascular elements.

On the basis of impressions with respect to the relative cellularity or vascularity, respectively, of their glomera, the 78 ears in which such formations occur have been subdivided; 55 of the ears have glomera classified as "Cellular," 23 have glomera classified as "Vascular" in type. Twenty-four of the 55 ears with glomera classified as "Cellular" are from females; for those classified as "Vascular" the corresponding figures are 7 out of the 23 ears. The difference in sex incidence in the two groups is not significant. The average ages for the two groups are, respectively: "Cellular," 40 years; "Vascular," 47 years. The overlap of age distribution in the two groups is so great that this difference of 7 years is, likewise, not significant. The two groups differ by only 0.2 in the average number of glomera per ear, a difference so slight that this breakdown of the observations, like those for sex and for age, affords no evidence of a relationship of the two types of histologic appearance to other items of the material examined.

Innervation of the glomus jugulare is entirely, or almost entirely, by non-medullated nerve fibers. When the plane of section is favorable for observation of the entering nerve, as it is in the case illustrated in Figure 3, the size of the bundle of nerve fibers seems large in proportion to the amount of tissue to be supplied. Silver stains also give the impression that the glomus jugulare has a rich innervation. Neither the silver stains made by me nor those Dr. James A. Foley, of the University of Alabama, kindly made for me, show nerve endings; they merely show that numerous non-medullated nerve fibers are present between the epithelioid cells. To determine the place and manner of termination of these nerve fibers it will probably be necessary to use material that has not been exposed to decalcification fluids and embedded in celloidin.

For the glomera along the course of the nerve of Jacobson, the source of the innervation is, without much doubt, the glossopharyngeal nerve. For glomera along the course of the nerve of Arnold, the innervation may hypothetically be by fibers of the vagus nerve proper or by fibers of the glossopharyngeal nerve, via its anastomotic connection or connections with the nerve of Arnold. This possibility will be further considered later.

The blood supply of the jugular bodies is for the most part derived from the ascending pharyngeal artery by way of its tympanic branch. This branch accompanies the nerve of Jacobson and in the jugular fossa often gives off a branch that accompanies the nerve of Arnold. The anastomoses of these vessels with other small branches of the carotid system in the middle-ear region make it possible that the ascending pharyngeal artery is not the sole source of blood to all the glomus formations of the region, especially those in the descending part of the facial canal.

ANATOMIC DISTRIBUTION OF THE OBSERVED GLOMERA

The glomus jugulare is not constantly present in any of the anatomic locations in which it has been found in the material studied. In fact, the observed glomera, except for their close association with either the nerve of Jacobson or that of Arnold, display a marked degree of inconstancy in anatomic relations.

Glomus formations may be present along any portion of the nerve of Jacobson, from its origin from the glossopharyngeal trunk in the region of the petrous ganglion distally to where it becomes

Fig. 10.—Photomicrograph, at a higher magnification than in Figure 9, to reveal better the close relationship of the glomus to the nerve of Arnold, the subdivision of this glomus into numerous tiny lobules, and the nature of the tissue near it. A bit of the lumen of the jugular bulb is included at the lower left part of the picture.

continuous with the lesser superficial petrosal nerve near the geniculate ganglion of the facial nerve. The 135 glomera that have been found along the nerve of Jacobson in the 88 ears examined, are distributed as follows: Fourteen are near its origin or closer to its origin than to its entrance into the osseous canal (canaliculus tympanica) through which the nerve passes into the middle ear; 37 are in the adventitia of the jugular bulb near the inferior end of the tympanic canaliculus (in several instances two canaliculi are present, each transmitting part of the nerve); 54 are in the lumen of the tympanic canaliculus; 27 are along the promontorial course of the nerve; and three are along the portion that is superior, or distal, to the cochlear promontory. In 24 of the 88 ears of the material examined no glomus formation has been found along the course of the nerve of Jacobson; for 11 of these 24 ears the blocks sectioned did not include all regions in which glomera might be present along this nerve, so for only 13 of the ears is the negative finding regarded as reasonably definite.

The inconstancy of occurrence of the glomus jugulare in any particular place is well illustrated by the data for the portion of the nerve of Jacobson that lies in the mucosa of the cochlear promontory,

a region which is present and well preserved in all of the specimens examined. Eighteen of the 88 cars have a single glomus formation and three ears have more than one glomus each in the promontorial region; no glomus is present along the promontorial part of the nerve of Jacobson in the remaining 67 ears. Glomera are present bilaterally in the promontorial region in only four instances. Otherwise stated, the observations reported indicate that about one-tenth of all glomus formations in the ear regions are in the mucosa of the cochlear promontory, that about one-fourth of all ears have a glomus formation on the promontory, and that nearly two-fifths (17 out of 44) of all persons have such a structure on the promontory of one or of both ears.

The data for the portion of the nerve of Jacobson in the tympanic canaliculus are also of interest with respect to inconstancy of occurrence of the glomus jugulare. Slightly more than one-fifth (54 out of 248) of all glomera found in the material are in this short osseous canal; in 23 cases a single glomus is present, six canaliculi contain two glomera each, three contain three each, one contains four and one contains six glomera. The total number of ears with one or more glomus formations in the tympanic canaliculus is thus 34; the condition is bilateral in ten cases, unilateral in 14. The presence or absence of glomus formations in the osseous canal cannot be ascertained in five of the 88 ears examined, because the soft tissues had been torn out. The observations made indicate that a glomus jugulare is present in the tympanic canaliculus of one or of both ears in about a half (24 out of 44) of all persons.

Slightly more than half of the glomus formations that have been found in this material, 132 of the 248, are in the general region of the jugular fossa, most of them in the adventitia of the jugular bulb. The proportion of glomera in this region would doubtless be larger if all of the specimens examined had contained the entire dome of the jugular bulb.

Fifty-one of the glomera in the region of the jugular fossa are along the nerve of Jacobson (the tympanic branch of the glossopharyngeal nerve) between its origin, which may be from the ganglion or the trunk of the parent nerve, and its entrance into the tympanic canaliculus; 14 of these are near the origin. Eighty-one of the glomera found in the jugular fossa region are along this part of the course of the nerve of Arnold (the auricular branch of the vagus

Fig. 11.—Photomicrograph, at a very low magnification, of a "vertical" section of a human temporal bone, to show the location, and relations to other parts of the ear, of a glomus jugulare (indicated by the arrow) in the inferior end of a mastoid canaliculus that starts in the postero-lateral part of the jugular fossa. This glomus is along the course of the nerve of Arnold, which is in this instance divided into two portions (better seen in the next illustration).

nerve); most of them are in the postero-lateral part of the fossa, in the adventitia of this part of the dome of the jugular bulb (Figs. 9, 10, 11 and 12). In the sections of one ear three glomus formations found are near the origin of the nerve of Arnold from the ganglionic region of the vagus; two of these glomera are small, in the size classification used, the other is tiny. Histologically all three glomera are like the others in this ear, of the cellular type. From their location,

these three glomera could properly be called juxtavagal; and it may well be that ones similar to these have been described as juxtavagal paraganglia. Because the region of origin of the nerve of Arnold was not included in many of the temporal-bone blocks sectioned, the true frequency of occurrence of a glomus jugulare in this region cannot be determined from the material studied.

The course of the nerve of Arnold between the jugular fossa and the facial canal differs, in more than two-fifths of the ears of the present material, from that described for it in textbooks. Adequately to describe the variations in its course that have been observed during this search for glomus formations along the nerve of Arnold would require the writing of a separate paper. The points of special interest for the present study are: 1) two mastoid canaliculi may be present, each transmitting part of the nerve of Arnold; 2) when two canaliculi are present, usually one of them opens into the facial canal several millimeters below the other; 3) when only one canaliculus is present, it may be at the level of either the "superior" or the "inferior" canaliculus of most of the ears with two osseous channels for the nerve of Arnold; 4) a branch of the nerve of Arnold, even all of it (one specimen), may pass from the jugular fossa along the surface of the skull to the stylomastoid foramen and thus reach the descending facial canal. By this route, which may descriptively be termed the "external" one, the branch (or all) of the nerve of Arnold passes along an unnamed groove, on the base of the skull, medial and then postero-medial to the styloid process. This groove is inferior to, or infero-lateral to, the posterio-inferior quadrant of the tympanic sulcus, and its distance from the latter landmark varies greatly, being dependent on the degree of pneumatization of the hypotympanum and the size and shape of the jugular fossa. In "vertical" sections of this part of the temporal bone the groove shows as a "notch;" it is filled with dense fibrous tissue.

Only 32 of the 113 glomus formations found along the nerve of Arnold are on portions of its course further peripheralward than the jugular fossa.

In 14 ears a glomus is present in a mastoid canaliculus between the jugular fossa and the descending part of the facial canal; in each of two other ears more than one glomus is present in this region; the total is 19. The actual incidence of glomera along the canalicular part of the course of the nerve of Arnold is probably higher than is

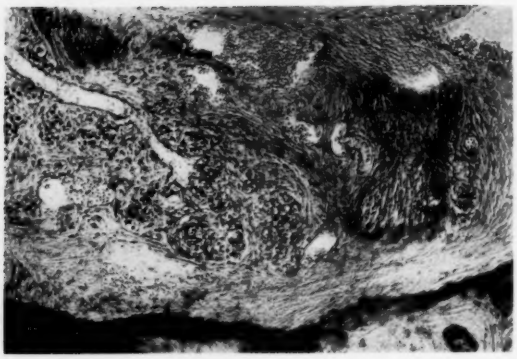

Fig. 12.—Photomicrograph, at a medium magnification, of the glomus jugulare whose location is shown in the preceding figure. The small blood vessel that is longitudinally cut in this section is a vein; tributaries to it from at least four of the lobules of the glomus can be identified.

indicated by the present data, because in a considerable number of the 88 ears examined a portion of the mastoid canaliculus (or canaliculi, if two were present) for the nerve was not included in the block of tissue sectioned. The portion missing is usually that part nearest the jugular fossa; in the ears in which all parts of the intraosseous course of the nerve have been included, glomus formations are most often present near its proximal end (Figs. 11 and 12).

Six glomus formations have been found along that part of the "external" course of the nerve of Arnold, in the unnamed groove (see above); three ears have one glomus each in this location, and one ear has three glomera. The actual incidence of jugular bodies in this region is probably much higher than is indicated by the examples found, because the groove in question was not included in many of the blocks sectioned. At the time the temporal bones were trimmed for sectioning, there was no reason to expect that the region of the unnamed groove would ever be of interest for study.

A total of seven glomera have been found in the descending part of the facial canal; in one ear three small glomus formations are present (Figs. 13 and 14), and in each of four other ears there

is one glomus. All seven of the glomus formations in the facial canal are without doubt associated with the auricular branch of the vagus rather than with the nearby facial nerve. In only a few instances has the course of the nerve of Arnold beyond the facial canal been examined for glomus formations; the blocks seldom contained this region of the temporal bone.

The nerve of Arnold (auricular branch of the vagus) receives anastomotic contributions from the glossopharyngeal nerve and from the cervical sympathetic trunk. The anastomotic branch, or branches, from the glossopharyngeal nerve may arise from its trunk, from the region of the ganglion of the trunk, or from the nerve of Jacobson. Beyond their regions of juntion with the nerve of Arnold the fibers contributed by an anastomotic element cannot be definitely traced, or identified, in the sections of the present material. In numerous instances I have nevertheless had the impression, while examining the sections, that the nerve fibers to a glomus were from an anastomotic contribution to the nerve of Arnold; in a few instances a glomus formation is alongside an anastomotic branch of glossopharyngeal origin near its junction with the nerve of Arnold. It is therefore entirely possible, in my opinion, that part or perhaps all of the glomus formations along the course of the nerve of Arnold are actually innervated by fibers from the glossopharyngeal nerve instead of from the vagus. If so, a glomus jugulare, whether along the nerve of Jacobson or the nerve of Arnold, is similar to the better known carotid body in source of innervation as well as in histologic appearance.

In closing this presentation to clinicians of a frankly anatomic paper, I wish to point out one relation of the anatomic facts to clinical problems. The locations in which the normal glomus jugulare may be present are such as to account satisfactorily for all the differences in order of symptoms that have been reported for patients with glomus-jugulare tumors, also sufficient to account for all the differences in site of apparent origin of the growth that have been found at operations to remove such tumors. Certainly the first symptom caused by the tumorous growth of a glomus in the facial canal, pressing on the facial nerve, will not be the same as the first symptom caused by growth of a glomus on the cochlear promontory, interfering with ossicular movements, or by the tumorous enlargement of a glomus near the large nerve trunks in the anterior part of the jugular foramen. In this respect, the glomus jugulare is an-

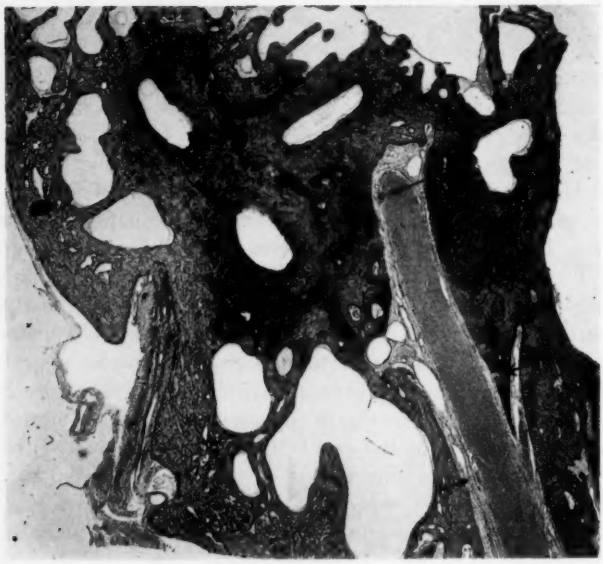

Fig. 13.—Photomicrograph, at a very low magnification, of part of a "vertical" section of a human temporal bone, to show the location of the three glomus formations (indicated by arrows) that are present in this ear in the descending part of the facial canal, in the connective tissue around the facial nerve. Their innervation, however, is from the nerve of Arnold, which crosses the facial nerve in this part of its course. The main stem of the nerve of Arnold can be seen to the left of the facial nerve, somewhat below the middle of the picture. On the right side of the picture of the facial nerve, across from the lower glomus, the origin of the chorda tympani nerve may be seen, also the lower end of its special osseous canal; no glomus formations have been found along the chorda tympani nerve.

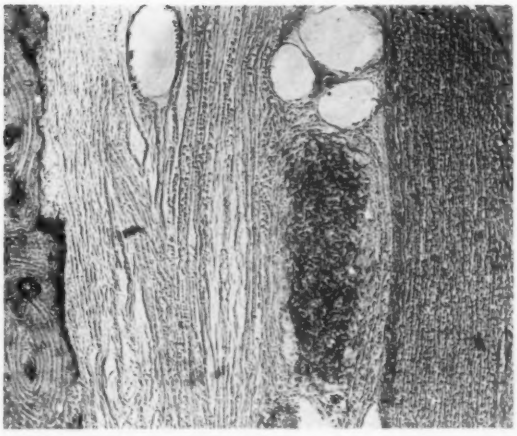

Fig. 14.—Photomicrograph, at a medium magnification, of the lower of the three glomus formations shown in Figure 13. The edge of the bony wall of the facial canal and a portion of the longitudinally sectioned facial nerve are included in the picture. Many of the glomus formations are as small as is this one; histologically all are similar.

other and a good example of how anatomic knowledge may aid in the solving of clinical problems.

SUMMARY

Terminologies that have been proposed are discussed and reasons are given for favoring use of the terms employed in the title of this paper.

The glomus jugulare has been sought for in the histologic sections of 88 human temporal bones (both ears of 44 persons). The average number of jugular bodies found in this material is slightly less than three per ear.

Jugular bodies occur with almost equal frequency along the courses of the nerve of Jacobson (tympanic branch of the glossopharyngeal nerve) and of the nerve of Arnold (auricular branch of the vagus). Innervation of the glomus formations along the nerve of Arnold may be actually by fibers received through anastomotic

branches from the glossopharyngeal nerve; this point cannot be definitely ascertained from the present material.

Somewhat more than half of the glomus formations found are in the adventitia of the dome of the jugular bulb, along the jugular fossa part of the course of one or the other of the two nerves named above; and another fifth are in the osseous canal (tympanic canaliculus) through which the nerve of Jacobson enters the middle ear from the jugular fossa.

About one-fourth of the ears have a glomus formation in the mucosa of the cochlear promontory, along the tympanic plexus portion of the course of the nerve of Jacobson. In three instances a glomus is present superior to th promontory, near the continuation of the nerve of Jacobson into the lesser superficial petrosal nerve.

Jugular bodies may be present also along the course of the nerve of Arnold beyond the jugular fossa, at least as far peripherally as the descending facial canal, in which seven examples have been observed.

Between the jugular fossa and the descending facial canal the nerve of Arnold may pass in courses not described in textbooks; jugular bodies have been found along each of the optional routes of this nerve, including the route external to the skull.

In none of the locations in which a glomus jugulare may be present is the structure of constant occurrence.

Histologically the glomus jugulare closely resembles the carotid body. Each glomus consists essentially of numerous small blood vessels, capillary or pre-capillary in size, and of epithelioid cells in the spaces between blood vessels. The proportion of epithelioid cells to blood vessels may differ considerably in individuals.

Jugular bodies differ in size from about 1.5 mm in the longer dimension to about 0.1 mm; four-fifths of them are in the size range from 0.5 mm downward.

Neither race, sex or side of head is significantly related to the number, distribution, size or histologic appearance of jugular bodies found in the material examined. Age does seem to be related to the number of jugular bodies present, with the period of mid-adult life that of the highest incidence.

The differences in order of clinical symptoms that have been reported for patients with glomus-jugulare tumors, also the differ-

ences in apparent site of origin found at operations to remove such tumors, can all be satisfactorily explained by the differences in the observed locations of normal jugular bodies, had they undergone an abnormal enlargement.

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XCIII

SURGICAL REPAIR OF THE PERFORATED EAR DRUM

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Many methods have been devised in an attempt to close persistent openings in the ear drum. In order to stimulate and guide epithelization, these techniques employ the use of a caustic to freshen the margins of the perforation and some type of foreign substance or skin[1, 2] is used to cover the opening. Unfortunately, these procedures are often unsucessful in central perforations and cannot be used when the margin is involved.

A patient consulted me some seven years ago, who had had a fenestration elsewhere. Following the operation the patient had heard very satisfactority for approximately one month and then acute otitis media developed. The hearing dropped to the preoperative level and the patient noticed a severe tinnitus. Although the drainage subsided three months later, the hearing did not improve and the tinnitus remained.

My examination revealed the ear drum to be totally absent. There was no discharge from the middle ear and the fixed stapes could be readily visualized and palpated. The fistula test was strongly positive and an audiogram revealed a mixed type of hearing impairment.

Cocainization of the medial wall of the middle ear temporarily alleviated the severe tinnitus. In view of this favorable finding it was decided to destroy the tympanic plexus. Since the fistula test was strongly positive and the cochlear nerve function reasonably good, the thought of using a thin, full thickness skin graft over the middle ear region seemed feasible. I have successfully used such a graft many times to cover the eustachian tube orifice in radical mastoid

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surgery and to close the attic opening in cases of congenital ear canal atresia. How an adequate blood supply is maintained to the graft when placed over an opening and what ultimately lines its under surface continues to be a matter of conjecture.

After discussing all of the possibilites thoroughly with the patient, the mucous membrane over the promontory of the cochlea was removed together with the tympanic plexus. A thin, full thickness skin graft taken from the postauricular area was used to cover the entire middle ear region extending to the annular ring and for a millimeter or two around the ear canal wall.

Although the graft healed in its entirety, unfortunately, the patient's tinnitus and hearing level remained unchanged.

It has been my misfortune to tear the ear drum at the time the head and neck of the malleus was removed in several fenestration cases. If the laceration was not too extensive healing has occurred after simply approximating the drum edges. In others, when the laceration was more extensive, blood was floated into the middle ear and cigarette paper, or some other foreign substance, was used to cover the opening in the ear drum. In these cases, healing often did not occur and consequently the hearing did not improve to the serviceable level.

Some three years ago, such an injury occurred while clipping the malleus in a case with a rather large pre-existing healed central perforation. Since the laceration was too extensive to hope for spontaneous closure, it was decided to immediately curette the promontory and apply a thin, full thickness graft over the area.

Under adequate magnification, three equally spaced incisions were made in the remaining ear drum to the annulus. The margins of the drum then dropped to the medial surface of the middle ear. A small eye spud was used to remove the mucous membrane from the promontory of the cochlea. The membrane about the stapes and round window regions was carefully avoided so as not to create scar tissue in these areas.

A thin, full thickness skin graft removed from the postauricular area was then placed over the denuded bone on the medial surface of the middle ear in such a way as to cover the ear drum opening. The perforation, as well as the central middle ear air space, was completely

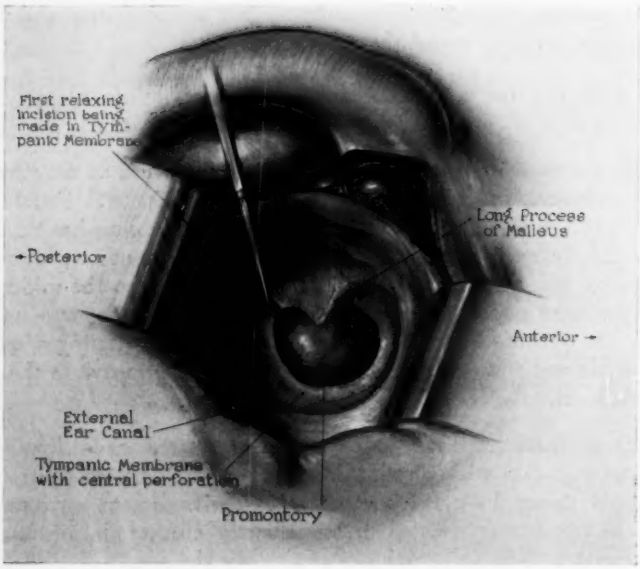

Fig. 1.—Stellate incisions are made from the perforation to the periphery of the drum.

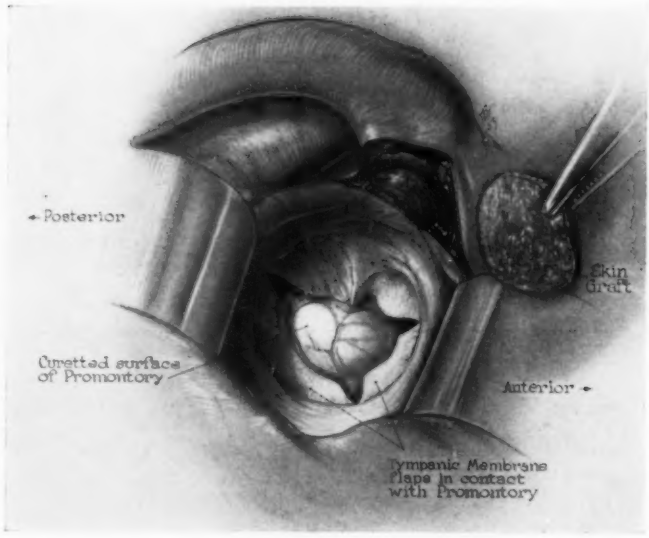

Fig. 2.—Completed incisions and curettement of the promontory.

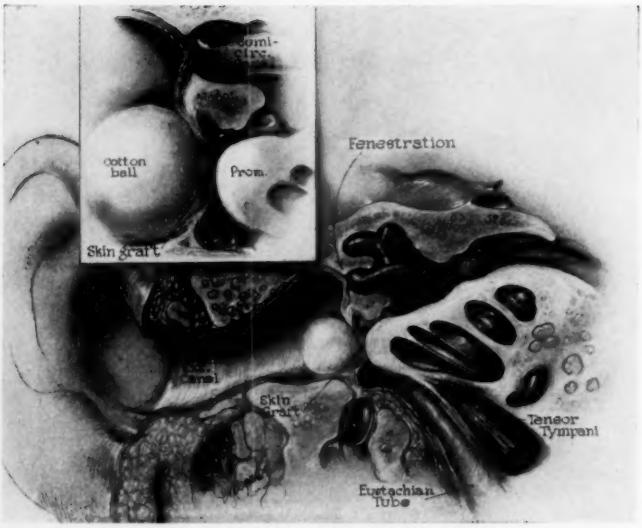

Fig. 3.—Skin graft applied to the promontory.

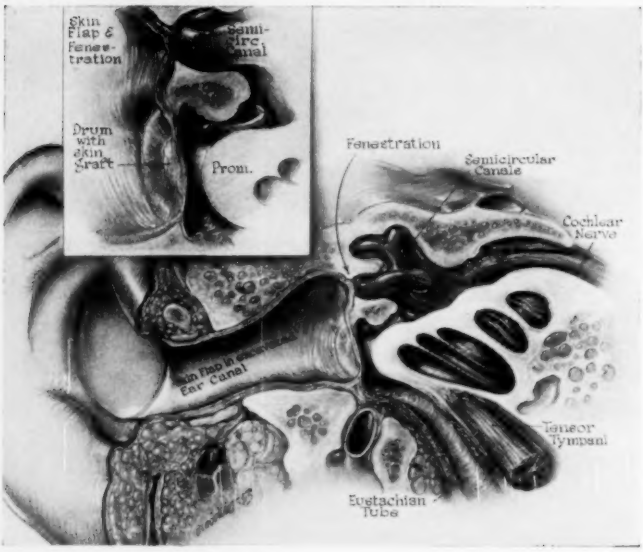

Fig. 4.—The skin graft may spontaneously detach itself from the underlying promontory, as above.

obliterated by this procedure. A cotton pledget was used to secure the skin graft firmly in place.

POSTOPERATIVE COURSE

The cotton pledget was removed on the fifth postoperative day, together with the remaining fenestration packing. A healthy appearing skin graft was found to be adherent to the promontory, which gave the appearance of a completely retracted and thickened scarred ear drum. Since the ear drum remained mobile between the graft edges and the annular ring, a small peripheral sealed middle ear air space was created.

Persistent drainage from a small granulating area in the mastoid tip region necessitated reopening of the endaural incision some six months after the initial surgery. The granulations were removed and a skin graft was placed over the denuded area.

This procedure provided an opportunity to observe and photograph the ear drum graft. It was interesting to note the drum had released itself from the promontory and was again entirely mobile. Apparently, mucous membrane must have relined the bone over the promontory, as well as the under surface of the thin, full thickness graft.

In a third and a fourth case, the ear drum is still adherent to the promontory.

SUMMARY

1. This technique of curetting the promontory and applying a skin graft seems to provide a positive method of repairing extensive ear drum lacerations which may occur during the fenestration operation.

2. This procedure may also prove of value in closing both central and marginal perforations in selected cases of inactive chronic otitis media.

1136 N. 6TH ST.

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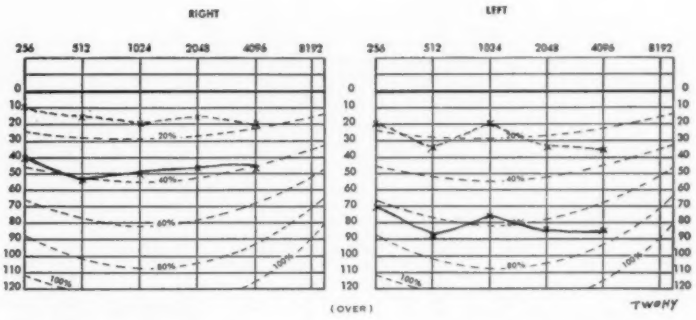

Fig. 5.—Preoperative audiogram, Case 1. (Dashed line, bone conduction)

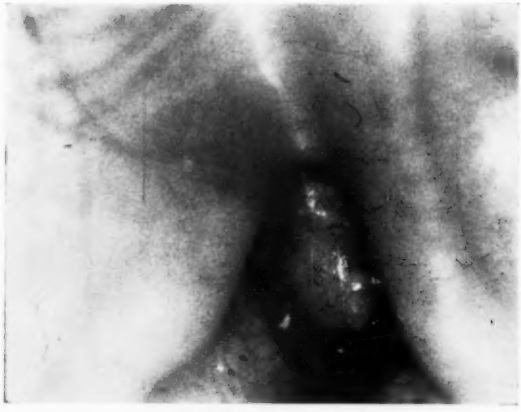

Fig. 6, Case 1.—Healed skin graft covering the middle ear and tubal orifice.

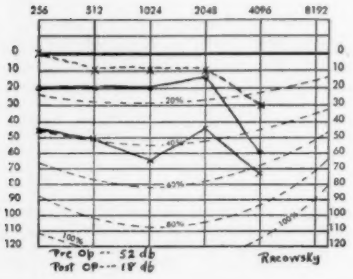

Fig. 7, Case 2.—Preoperative and postoperative audiogram. Preoperative level, 52 db, February 28, 1951. Postoperative level, 18 db, January 16, 1952. Bone - - - - -; Preop. Air —x—x; Postop. Air —o—o.

Fig. 8, Case 2.—Note the intact ear drum with the healed skin graft obliterating the perforation.

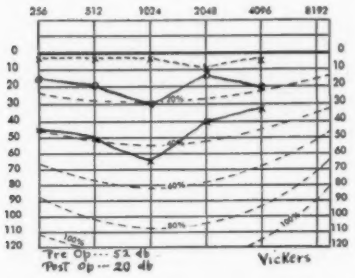

Fig. 9, Case 3.—Preoperative and postoperative audiogram. Preoperative level, 52 db, September 29, 1949. Postoperative level, 20 db, January 8, 1951.

Fig. 10, Case 3.—Note healed skin graft covering the site of the perforation.

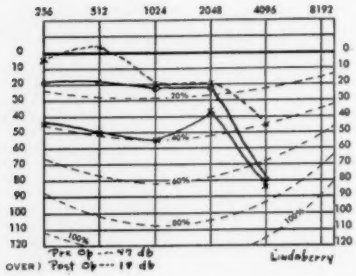

Fig. 11, Case 4.—Preoperative and postoperative audiogram. Preoperative level, 47 db, June 18, 1952. Postoperative level, 18 db, March 13, 1953.

Fig. 12, Case 4.—Note extensive healed marginal skin graft covering the site of the perforation.

XCIV

THE DEVELOPMENT OF THE OTIC CAPSULE IN THE REGION OF THE COCHLEAR FENESTRA

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In a series of preceding articles the authors reported the results of their otological studies as portions of an inclusive investigation of the developmental anatomy and adult structure of the human ear. These reports, planned for presentation at meetings of the American Otological Society, dealt chiefly with the following subjects: the development of the auditory ossicles;[1, 4] the development and normal adult anatomy of the fissula ante fenestram;[5] the aberrant form and pathological contents of the fissula;[6] the development of the otic capsule and of the extracapsular tissues.[4, 8] Subsequently, the original program was extended to include those special portions of the capsule in which late histological alteration regularly occurs; these are the regions of the cochlear aqueduct and periotic duct,[9] of the tympanic wall of the lateral semicircular canal (the region of surgical fenestration)[2] and of the cranial aperture of the vestibular aqueduct.[3, 11]

In the tympanic wall of the lateral semicircular canal the process of ossification begins to embark upon a special course when the fetus has reached the stage of four or five months. Within a period of four weeks thereafter, the recently formed outer (periosteal) layer has been largely removed, together with part of a neighboring portion of the middle layer (endochondral and intrachondrial bone). Following this stage, new membrane bone is added on the tympanic

From the Department of Anatomy of the University of Wisconsin and the Department of Anatomy of Northwestern University Medical School (Contribution No. 600 from the latter).

surface to restore a smooth contour. Similarly, in the case of the vestibular aqueduct, the cranial aperture is remodelled in late fetal and early postnatal stages—in response to the changing angle and the concurrent expansion of the contained otic (endolymphatic) sac. The original bone is destroyed, the orifice of the aqueduct thereby widened, and the fovea for the endolymphatic sac is deepened. Subsequently, membrane bone is deposited to form a newly-lined channel which is but little larger than the sac itself. At the same time, endochondral bone rapidly increases in amount to render the texture petrous, and periosteal bone is added on the cranial aspect of the ledge which guards the orifice. The inner (endosteal) layer remains unchanged, as it does also in the area of the lateral semicircular canal.

In the development of the capsule in the region of the cochlear fenestra (round window) the process is not one in which a portion of the capsule, already formed, undergoes partial destruction, then reestablishment through production of bone not originally present in the area; rather, it is a case of morphogenesis in which growing cartilage, late to ossify, largely determines the conformation of the region.

In the present article, the authors will describe the chief steps in the development of this fenestral portion of the otic capsule. This region, like that of the fissula ante fenestram, is one in which cartilage plays a very important part in the establishment of adult form.

MATERIAL AND METHODS

In keeping with the plan followed in the pursuit of several earlier phases of this investigation, the observations recorded in the current article are based upon the examination of a large number of series of sections in the Otological Collection at the University of Wisconsin. Representative stages were selected for description and illustration. The figures are photomicrographs of sections (Figs. 1 and 2) or schematized adaptations thereof (Fig. 9), and detailed drawings of reconstructions (Figs. 3 to 8). The reconstructions were prepared at a magnification of 20 or 40 diameters; the drawings of the "models" were made natural size or twice the natural size of the reconstruction.

OBSERVATIONS AND DISCUSSIONS

Development of Otic Capsule. For the reader who may be unfamiliar with the content of the authors' previous publications, the

following brief review of the general features of capsular devlopment will provide information essential to an understanding of the special part played by the cartilage in the formation of the cochlear fenestra.

So rapid is the development of the otic capsule in man, that it attains adult dimensions when the fetus has just reached the midpoint in its intrauterine existence. But despite the fact that the capsule retains fetal dimensions throughout life, it acquires a thick investment of extracapsular periosteal origin and, as a consequence, becomes the labyrinthine core of the so-called petrous portion of the temporal bone.* The otic capsule is also unique in being formed from numerous primordially independent ossification centers.[7, 10] Bone spreads from each of these originally separate centers, the process thus differing from that which takes place in a typical long bone, in the growth of which initial ossification spreads from the middle of a diaphysis toward terminal epiphyses. Fusion between neighboring centers in the otic capsule is marginal and complete; no zones of secondary, or epiphyseal, growth exist to permit continued expansion. Fusion of the centers, with ultimate obliteration of fusion-lines between contiguous areas of ossification, early converts the otic capsule into an osseous unit. The otic capsule is exceptional, too, in the manner in which bone, already formed, becomes pneumatized through the invasion of mucous membrane, and in the retention, within its middle layer, of a considerable fraction of its primitive cartilage in the form of intrachondrial bone lodged in a far more extensive bed of endochondral bone. This tissue is never converted into bone of haversian structure; neither are the successive laminae of the periosteal bone (through the production of which the full dimensions of the adult temporal bone is ultimately attained), nor the endosteal layer (which constitutes an unchanging shell for the labyrinthine system of canals).

Of the three layers of capsular bone, the middle layer is the most remarkable: it is the only portion of the otic capsule that is preceded in its morphogenesis by cartilage; it is made up of two kinds of osseous tissue, namely, intrachondrial and endochondral

*While topographically convenient, the designation "pars petrosa" is a misleading term as applied to that part of the temporal bone between the squama and the pars mastoidea. Actually only the otic capsule is petrous; certainly neither the portion occupied by marrow nor by air-cells deserves such a designation.

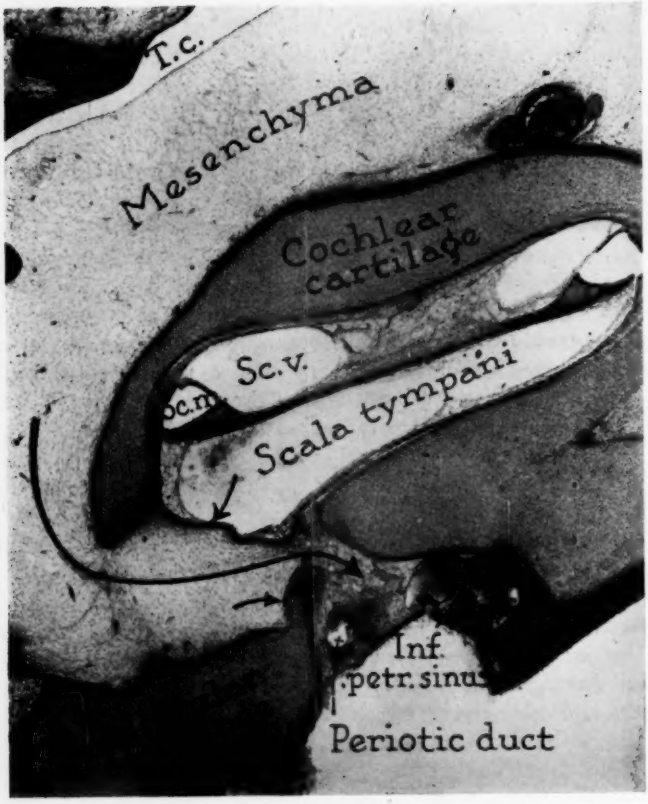

T.c.
Mesenchyma
Cochlear cartilage
Sc.v.
Scala tympani
Inf. petr. sinus
Periotic duct

Fig. 1.—Photomicrograph of a transverse section through the otic capsule in the area of the cochlear fenestra (round window). X 40. Wisconsin series 162. Fetus of 12 weeks (84 mm), slide 12, section 4.

Between the cochlear and canalicular divisions of the capsule a mesenchyma-filled space, the tympanimeningeal hiatus passes (along the course of the curving arrow) from the region of the future middle ear to the cranial cavity. A cartilage bar (at lower small arrow) has just appeared at the internal extremity of the primordial fossula of the cochlear fenestra; it will ultimately separate the fossula from the periotic (perilymphatic) duct, the glossopharyngeal nerve and the inferior petrosal sinus. The secondary tympanic membrane is discernible (at upper small arrow) between the scala tympani and the primordial fossula.

Abbreviations, etc., in this and in succeeding figures: *Amp. post. semic. canal,* ampulla of posterior canal; *A. p. s. d.,* ampulla of posterior semicircular duct; *B.,* bone; *B. m.,* basilar membrane; *C. b.,* cartilage bar; *C. d. s. sc. m.,* cul de sac of scala media (cochlear duct); *C. d. s. sc. t.,* cul de sac of scala tympani; *Cochl. fenest.,* cochlear fenestra; *F. c. f.,* fossula of cochlear fenestra; *Gangl. IX n.,* ganglion of the ninth (glossopharyngeal) cranial nerve; *Immat. Cartil.,* immature cartilage; *Inf. petr. sinus,* inferior petrosal sinus; *Lat. semic. canal,* lateral semicircular canal; *L. s.,* lateral sinus (of dura mater); *L. s. d.,* lateral semicircular duct; *M. m.,* mucous membrane; *P. d.* or *Per. duct,* periotic duct; *Ph.,* pharynx; *P. s. c.,* or *Post. semic. canal,* posterior semicircular canal; *P. s. d.,* posterior semicircular duct; *R. m.,* Reissner's (vestibular) membrane; *Sc. m.,* scala media; *Scala tymp., sc. t.,* or *Sc. tymp.,* scala tympani; *Sc. v.,* scala vestibuli; *Sp. l.,* spiral ligament; *S. t. m.,* secondary tympanic membrane; *T. c.* or *Tymp. cavity,* tympanic cavity; *Utr.,* utricle; *V.,* vein (of cochlea); *Vest.,* vestibule; *IX,* ninth (glossopharyngeal) nerve. *1* indicates the "primary" osseous spiral lamina; *II,* the secondary lamina; *1, 2* and *3* indicate, respectively, the outer (periosteal), the middle (intrachondrial and endochondral), the inner (endosteal), layers of bone; *4* indicates membrane bone.

constituents. The intrachondrial bone appears before the endochondral. The former is present in the fetus of 16 weeks, and attains maximum development at midterm. Soon after the islands of intrachondrial bone attain widespread distribution in the capsule, the formation of endochondral bone is initiated; the latter is deposited by osteoblasts upon the intrachondrial bone, which, being thus embedded, is retained throughout life as calcified remnants of the cartilage matrix of the primordial capsule.

Employing stages selected for the present study, the above-described step may be traced from the 84-mm fetus to the adult.

The otic capsule of the 84-mm fetus is still entirely cartilaginous (Fig. 1). Ossification centers have appeared in the fetus of 126 mm on the tympanic wall and the latter's continuation into the fossula of the cochlear fenestra (Fig. 2b); the definitive layers of bone are not yet formed.

The three typical layers are present in the fetus of 167 mm (Fig. 2c). The outer (periosteal) layer is already undergoing thickening (Fig. 2c at 1); the inner (endosteal) stratum is thin, and is destined to remain so (Fig. 2c, at 3); the middle layer still consists wholly of unevenly and sparsely distributed intrachondrial bone spread through a considerable bed of primitive marrow (Fig. 2c, at 2). At this stage the formation of the layers is far from complete, and a considerable fraction of the capsule is still cartilaginous.

In the fetus of 215 mm the chief advance is evidenced in the outer layer; this layer has undergone a considerable increase in thickness (Fig. 2d). The middle layer shows no histological advance, neither does the inner stratum.

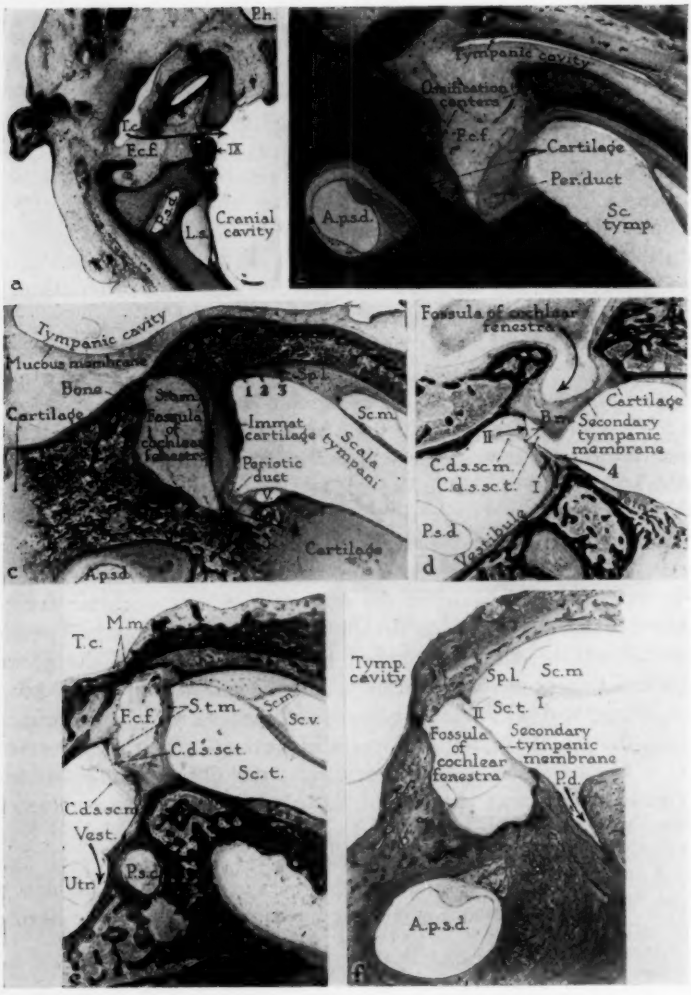
In the fetus of 305 mm some endochondral bone has been deposited on the intrachondrial spicules, and upon the internal aspect of the outer and inner layers of bone; however, so slow is the production of endochondral bone that the middle layer in some portions of the capsule of the newborn (Fig. 2e) could be mistaken for a much earlier stage in capsular morphogenesis.

Postnatal development is rapid; the middle layer is petrous in the infant, having assumed virtually the osseous character of the adult (Fig. 2f).

Development of Fenestra and Fossula. In the adult the entire labyrinth is encased in the otic capsule, except for the distal part of

the otic (endolymphatic) sac, the meningeal end of the periotic (perilymphatic) duct, and the tympanic end of the scala tympani, which latter is closed by the secondary tympanic membrane. The original cartilaginous otic capsule, which arises in human embryos between the 20-mm and 40-mm stages (that is, between the seventh and ninth week of intrauterine life), does not cover the internal ear so completely. Thus, in the early fetus in the region of the future cochlear fenestra, and in the surrounding area, a capsular wall is wanting. The gap which exists in the capsule at this early period is occupied by mesenchyme in which lie the arch of the first turn and cul de sac of the scala media (cochlear duct) and the ganglion of the glossopharyngeal nerve; in it, too, are destined to develop the scala tympani, the secondary tympanic membrane, the fossula of the cochlear fenestra, part of the tympanic cavity (middle ear), the periotic (perilymphatic) duct and accompanying vein, and the meningeal tissue in which are situated the glossopharyngeal nerve and its ganglia. This wide mesenchymal area between the cochlear and canalicular portion of the capsule will hereinafter be called the tympanomeningeal hiatus (area indicated by long arrows in Figs. 1 and 2a).*[10] The prime factor in the subdivision of this cleft is a late-developing cartilaginous bar, or partition, which, projecting from the capsular wall of the posterior semicircular ampulla across this area, extends cranialward to the floor of the bony cochlear fenestra (round window). This bar divides the area into a meningeal portion (containing the glossopharyngeal nerve and ganglion, the periotic duct and the accompanying vein), and the tympanic portion (occupied by the end of the scala tympani, the secondary tympanic membrane, the fossula of the cochlear window and a part of the middle ear). The partition, which later ossifies and expands, together with periosteal bone from the rest of the capsule, as well as some membrane bone, will eventually subdivide the tympanomeningeal hiatus in such a way as to delimit, or encase, the above-mentioned structures. To the morphogenesis of this part of the capsule, which begins at about the 40-mm stage, the description will now be devoted.

*The term "tympanomeningeal hiatus" would seem to be appropriate, since the interval brings the region of the future tympanic cavity into continuity with that of the brain and the latter's investments. "Tympanoencephalic" might, on topographical grounds, be equally suitable. Were the basis of terminology to be histological, the name "submuco-meningeal" could be chosen.


Ph.
T.c.
F.c.f.
IX
P.s.d.
L.s.
Cranial cavity
a
Tympanic cavity
Ossification centers
P.c.f.
Cartilage
Per.duct
A.p.s.d.
Sc. tymp.
Tympanic cavity
Mucous membrane
Bone
Cartilage
S.t.m.
Fossula of cochlear fenestra
1 2 3
Sp.l.
Immat. cartilage
Sc.m.
Scala tympani
Periotic duct
V
Cartilage
A.p.s.d.
c
Fossula of cochlear fenestra
Cartilage
II
B.m.
Secondary tympanic membrane
C.d.s.sc.m.
C.d.s.sc.t.
I
4
P.s.d.
Vestibule
d
M.m.
T.c.
F.c.f.
S.t.m.
Sc.m.
Sc.v.
C.d.s.sc.t.
Sc. t.
C.d.s.sc.m.
Vest.
Utr.
P.s.d.
e
Tymp. cavity
Sp.l.
Sc.m
II
Sc.t.
I
Fossula of cochlear fenestra
Secondary tympanic membrane
P.d.
A.p.s.d.
f

Figs. 2a to 2f.—Photomicrographs of transverse sections through the otic capsule in the region of the fossula of the cochlear fenestra in 6 specimens. Wisconsin series. X 20. Fig. 2a, fetus of 9 weeks (40 mm), series 168, slide 6, section 10; Fig. 2b, fetus of 16 weeks (126 mm), ser. 11, sl. 11, sect. 3; Fig. 2c, fetus of 20 weeks (167 mm), ser. 105, sl. 10, sect. 4; Fig. 2d, fetus of 24 weeks (215 mm), ser. 62, sl. 15, sect. 8; Fig. 2e, newborn, ser. 124, sl. 12, sect. 8; Fig. 2f, adult of 19 years, ser. P29, sect. 420.

Fig. 2a.—The otic capsule in the fetus of 9 weeks is still entirely cartilaginous. Mesenchymal tissue occupies the "space" of the tympanomeningeal hiatus (along the course of the arrow), between the cochlear and canalicular divisions of the capsule which passes without interruption from the tympanic cavity to the cranial cavity. Vacuolization (at *) predicts the formation of the scala tympani.

Fig. 2b.—In the fetus of 16 weeks the secondary tympanic membrane forms one boundary of the deep fossula; the latter is not yet pneumatized. The secondary tympanic membrane is attached at this level to the cartilage bar. The cochlear vein is medial to the partition formed by the cartilage bar, which has subdivided the original tympanomeningeal hiatus.

Fig. 2c.—The fetus of 20 weeks, in which the growing cartilage forms the lower rim of the fenestra. A projection of membrane bone (at 4) predicts final ossification of the fenestral wall. Delimitation of the original hiatus has taken place to a stage at which the periotic duct and cochlear vein are situated on the cochlear aspect of the developing secondary tympanic membrane. The typical layers have appeared in the wall of the otic capsule.

Fig. 2d.—In the fetus of 24 weeks the cul de sac of the scala tympani is continuous with the tympanic scala itself around the curving surface of the secondary tympanic membrane. The prolongation of the scala media is not here continuous with the main portion of the same duct, since its arciform course carries it to more superior level (and above the transverse level of the section). The osseous laminae (at I and II) are formed in membrane bone (at 4). The basilar membrane stretches across the vestibular fissure between their facing free edges. Ossification has produced a channel for the cochlear vein on the wall of the basal turn of the cochlea and for similar vessels of the vestibule.

Fig. 2e.—In the newborn the fossula of the cochlear fenestra is pneumatized. The membrane, because of its arching form, appears as the roof of the fossula (cut at two points in the section). The scala tympani and the scala media are carried over the horizontal portion of the membrane to appear on the vestibular aspect, each as a cul de sac. The prolongations of the two scalae are separated by the conjoined osseous spiral laminae.

Fig. 2f.—The secondary tympanic membrane, of adult form and structure in the newborn, is attached to the margin of the cochlear window on the fossular side of the crista of the cochlear fenestra. The periotic duct leaves the scala tympani on the cochlear side of the crest, within the canaliculus. The osseous spiral lamina (at I) offers support to one extremity of the basilar membrane. The thin secondary bony lamina (at II) gives attachment to the membrane and also to the spiral ligament. In its now mature form, the bone of the original otic capsule, and that which has been added to its tympanic surface, possess true petrous character.

40-*mm Fetus*

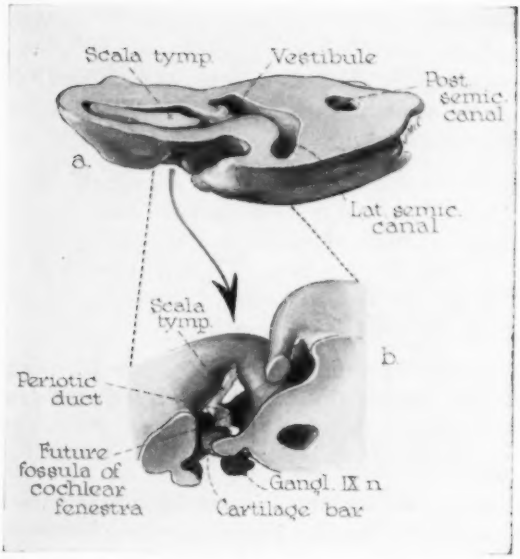
In the fetus of 40 mm (9 weeks) the capsule is definitely formed in cartilage; its divisions, canalicular and cochlear, are, however, separated in their lower part by the wide mesenchyma-filled interval (the tympanomeningeal hiatus) which passes without interruption from the area of the developing tympanic cavity anterolaterally to that of the cranial cavity posteromedially (Fig. 2a, along the course of the arrow). This interval is so extensive in the 40-mm stage that it includes also the rarefying tympanic extremity of the scala tympani (Fig. 2a at *), and the somewhat denser tissue of the future secondary tympanic membrane (Fig. 2a, between the asterisk and the abbreviation *F. c. f.*) . As already mentioned, the hiatus will later become subdivided into the fossula of the cochlear fenestra, the cochlear aqueduct, the channel for the cochlear vein and the canal which transmits the glossopharyngeal nerve. At this stage the fossula is indicated by an initial rarefaction of the mesenchymal tissue.

Although the entire endolymphatic (otic) duct-system is already present and is represented by the semicircular ducts and the middle scala, surrounding spaces for the perilymphatic (periotic) channels have not yet appeared to form the semicircular canals and the vestibular and tympanic scalae; in the cochlear division of the capsule, initial vacuolization is evident around the scala media (Fig. 2a at *).

50-*mm Fetus*

Somewhat later than the stage just described, that is, in the fetus of 50 mm (10 wks.), the first step is taken toward subdivision of the mesenchyma-filled space into two main areas, an external (tympanic) and an internal (meningeal) area. This segregation is accomplished through the growth of a cartilage bar which, as shown in a reconstruction, has already appeared at the inferior margin of the wide channel (Figs. 3a and 3b). The bar arises from the capsule near the ampulla of the posterior semicircular canal and extends anteromedially toward the cochlea; then it bends upward toward the base of the future cochlear window.

Although the periotic duct may still be seen in the depths beyond the capacious fossula, the ganglion of the glossopharyngeal nerve is already situated internal to the cartilage bar.



Figs. 3a and 3b.—Drawings of a reconstruction of a segment of the otic capsule in a fetus of 10 weeks (50 mm); Wis. ser. 86. Fig. 3a, the reconstruction, seen from the tympanic side and somewhat from above; X 12.5. Fig. 3b, the fossular portion of the capsule enlarged, the reconstruction turned upward to permit a view into the fossula of the cochlear window; X 14.5.

The capsule is still entirely cartilaginous; restriction of the widely open tympanomeningeal hiatus has been initiated through the upward growth of the cartilage bar. The periotic duct (like the scala tympani, modelled as a solid) is seen within the capacious channel which passes from the future tympanic cavity to the cranial cavity. The ganglion of the glossopharyngeal nerve is already internal to the chondral bar.

62-mm and 84-mm Fetuses

In fetuses of 62 mm (11 weeks) and 84 mm (12 weeks) the cartilage bar has further invaded the originally broad hiatus between the cochlear and canalicular portions of the capsule.

The two main divisions of the broad channel, the tympanomeningeal hiatus, in the 84- mm stage (Fig. 1, along the course of the large arrow) are being further defined by the growth of the

cartilage bar (Fig. 1, at lower small arrow); the tympanic portion (Fig. 1, at reader's left) is more rarefied than the meningeal part (Fig. 1, at reader's right). The latter houses the cochlear duct, the cochlear vein, the inferior petrosal sinus and the glossopharyngeal nerve with its ganglion; the former contains the fossula of the cochlear fenestra, the secondary tympanic membrane and the tympanic extremity of the scala tympani.

The vestibular and tympanic scalae are clearly defined periotic channels in the 84-mm fetus. The periotic duct,* prolonged from the scala tympani, courses along the internal aspect of the delimiting bar (Fig. 1, at lower small arrow). The duct consists of loose reticular tissue continuous with the arachnoid tissues of the cranial cavity (compare Bast, 1946, Fig. 8).

The secondary tympanic membrane is already identifiable; it appears as a thin septum which separates the scala tympani from the mesenchyma-filled fossula (Fig. 1, at upper small arrow). The membrane passes between margins of the primordial cochlear window.

The fossula of the cochlear fenestra (along the midcourse of the large arrow in Fig. 1) is still occupied by mesenchyma, as is also the greater part of the future tympanic cavity.

100-*mm Fetus*

In the fetus of 100 mm (15 weeks) the cartilage bar has grown across the mesenchyma-filled channel; its tip has reached, and fused with, the basal portion of the cochlear division of the capsule.

126-*mm Fetus*

In the interval between the 100-mm and 126-mm stages, marked changes have taken place in the structure of the otic capsule; chief among these is the appearance of ossification centers in the capsule of the fetus of 126 mm (16½ weeks).

Already the secondary tympanic membrane has assumed the arching form which is characteristic of the adult ear. In its lower and

*The periotic duct (for which there is no BNA term) is the vacuolated space within the cochlear aqueduct (aquaeductus cochleae) or perilymphatic duct. The designation "duct" as thus employed is, of course, unfortunate since the channel is part of the periotic (perilymphatic) labyrinth, not of the otic (endolymphatic); its use should be limited to the latter system of epithelial spaces.

middle portions the membrane lies in an approximately vertical plane, whereas in its upper reaches the membrane follows a generally horizontal course, then turns slightly downward, to form a dome-shaped roof of the fossula of the cochlear fenestra.

Definitely established, too, is the important relation of scala tympani and scala media (cochlear duct) to the secondary tympanic membrane, and to the fossula and the vestibule: both scalae are prolonged over the horizontal part of the membrane. The caecal prolongation, or cul de sac, of the scala tympani would thus occupy the summit of the fossula, its floor being the secondary tympanic membrane and its roof the forerunners of the osseous spiral laminae. The arch of the scala media, situated next cranialward, passes over the cul de sac of the scala tympani—its floor being the basilar membrane or membranous part of the future spiral lamina. The scala media extends into the vestibule, there to end in a cul de sac.

The cochlear vein, still free on the wall of the cochlea (Fig. 2b), later becomes covered by bone (see fetus of 215 mm, Fig. 2d).

Several of the features of development, which together make the 126-mm fetus a crucial stage in the morphogenesis of the structures in the region of the cochlear fenestra, are more satisfactorily demonstrated by a reconstruction of the otic capsule (Figs. 4a to 4f) than they are by photomicrographs of sections. In this specimen, ossification of the capsule is taking place rapidly in the fenestral region; actually, areas of bone which have but recently appeared as Center No. 2 and Center No. 3 (of Bast's chronological enumeration),[7, 10] have already fused to form the roof and walls of the opening into the fossula of the cochlear fenestra (Figs. 4b to 4f); however, the floor of the aditus, late to ossify, is formed by the cartilage bar (Figs. 4d to 4f). This cartilaginous ledge has now attained such form and has established such relations with the neighboring structures as to show not merely the capsular zone from which it is derived and with which it fuses, but also to predict the following steps in development: (a) formation of a completely ossified fossula and cochlear fenestra; (b) separation, by the secondary tympanic membrane, of the scala tympani from the fossular space; (c) enclosure of the periotic duct and the cochlear vein in complete and wholly independent osseous channels. In these concurrent processes the following will take place: (a) the cartilage bar, by ascending on the fossular wall (Figs. 4d to 4f), will reduce relatively the dimensions

of the cochlear fenestra, then undergo ossification; (b) the horizontal part of the secondary tympanic membrane, arching beneath the cul de sac of the scala tympani (Fig. 4b), will be carried in the form of a canopy over the cupola of the fossula—its attachment superiorly thus being prevented from coinciding with the margin of the cochlear fenestra; (c) the periotic duct, which at this stage still occupies the tympanomeningeal hiatus (Figs. 4e and 4f), will become surrounded by bone of the cochlear aqueduct—ultimately extending, as a minute canal, along the core of the aqueduct from the medial wall of the scala to the inferior surface of the petrous portion of the temporal bone, there to communicate with the subarachnoid space; (d) similarly, membrane bone will surround the cochlear vein, which, in the 126-mm fetus, lies free in the space of the cartilaginous cochlea near the point of origin of the periotic duct (Figs. 4d and 2b).

Because the osseous spiral laminae are not formed at this stage, the periotic labyrinth seems (in the reconstruction) to be continuous with the tympanic cavity through the fossula of the cochlear fenestra (Figs. 4e and 4f).

The chief developmental step represented by the 126-mm stage is the upward growth of the tip of the cartilage bar to form the lower margin of the cochlear fenestra (Fig. 4e, at arrow 1) and to fuse with that portion of the wall of the promontory which forms the rim of the fenestra (Fig. 4e, at arrow 2); but the bar (Fig. 4e, at arrow 3) has not yet fused with that portion of the capsular wall (Fig. 4e, at *) which will eventually become the medial rim of the cochlear fenestra. Because of late fusion in the last-named area, the original mesenchyma-filled space is still undivided; as a consequence, in the region of the periotic duct, the tympanic and meningeal portions remain continuous (Figs. 4e and 4f). The cartilage bar is still part of the unossified canalicular division of the capsule; but the area of the cochlear division with which it now makes contact is composed of ossified tissue.

167-mm Fetus

In the fetus of 167 mm (20 weeks) the bar, still composed mainly of immature cartilage, is undergoing ossification in its basal portion (Fig. 2c); toward its free edge the cartilage fuses with the capsule. From a relatively bulky mass inferiorly, the bar ascends to a bluntly

rounded tip. Already, from the free margin of the cartilage, the secondary tympanic membrane ascends, first vertically, then horizontally—and in such a way as to permit the scala tympani to extend, as a cul de sac, into the cupola of the fossula, that is, superior to the membrane (compare newborn, Fig. 2e).

As in the case of the enlarging fovea for the endolymphatic sac, the osseous wall of the fossula of the cochlear window is incompletely formed at this stage; periosteal bone is wanting, the osseous spicules of the middle layer being exposed to the periosteum in the fossula (Fig. 2c).

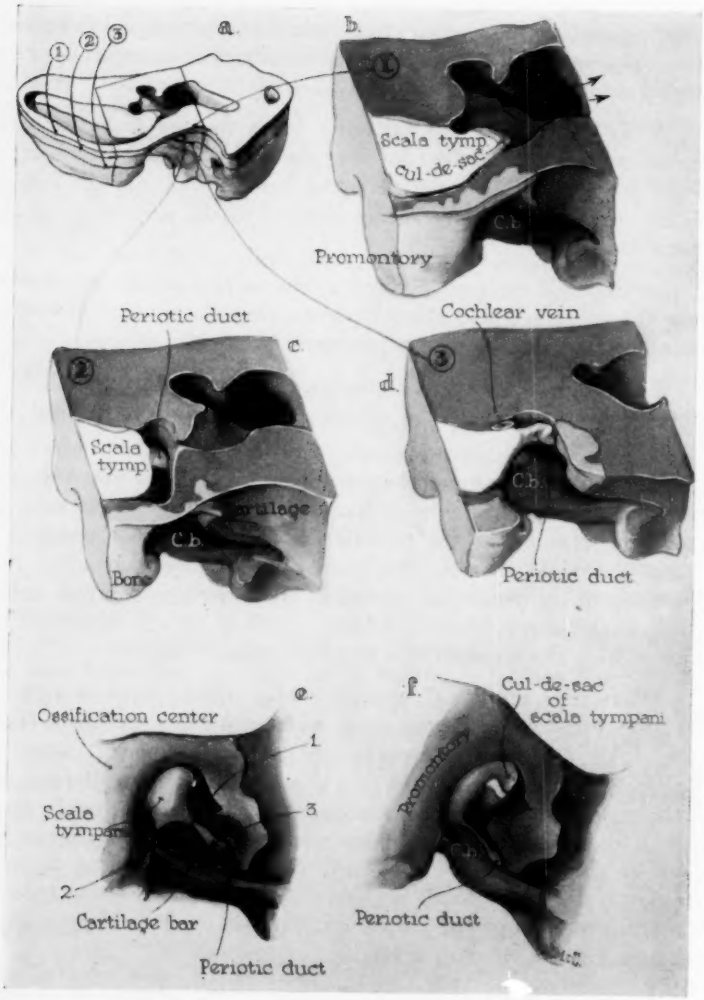
Membrane bone has appeared at the margin of the window to form the crista of the cochlear fenestra (Fig. 2c, at 4). However, osseous spiral laminae are not yet formed.

The tympanic cavity is expanding; the advancing epithelium is approaching the wall of the capsule, but has not yet invaded the fissula (Fig. 2c).

The periotic duct and the accompanying vein lie posteromedial to the developing rim of the cochlear window (crista fenestrae cochleae); the opening of the periotic duct into the scala tympani is closely related to the fenestral end of the cartilage bar (Fig. 2c). The tissue of the meningeal portion of the tympanomeningeal hiatus, which houses the primitive cochlear aqueduct, is still directly continuous with the mesenchyma of the tympanic portion.

Ossification of the otic capsule is best demonstrated in a reconstruction prepared from the serial sections of this specimen (Figs. 5a to 5c). As seen in the model, the tympanic (medial) aspect of the capsule has been converted into bone in the cochlear division and in the region of the internal acoustic meatus. However, in the territory of the fossula of the cochlear window, cartilage remains as the tissue of the actively growing bar. Relatively, the hiatus between the canalicular and cochlear divisions of the capsule has been reduced as a result of the upward growth of the cartilage bar (Fig. 5b, at 1; compare Fig. 3b, 50-mm stage).

In the canalicular division of the otic capsule, ossification (Center 2) has spread to such an extent as to include a portion of the ampullary region of the posterior semicircular canal and the basal part of the cartilage bar (Figs. 5a to 5c). Thus, the entire fossular wall has become ossified with the exception of that zone which is contributed


a.
b.
Scala tymp.
Cul-de-sac
Promontory
Periotic duct
Cochlear vein
c.
d.
Scala tymp.
Periotic duct
e.
Ossification center
1
3
Scala tympani
2
Cartilage bar
Periotic duct
f.
Cul-de-sac of scala tympani
Promontory
Periotic duct

Figs. 4a to 4f.—Drawings of a reconstruction of the lower portion of the otic capsule in a fetus of 16 weeks (126 mm); Wis. ser. 11. Showing the extent to which the cartilage bar has subdivided the tympanomeningeal hiatus into its ultimate portions. The secondary tympanic membrane is not included in the reconstruction. Fig. 4a, the entire reconstruction seen from the tympanic (lateral) aspect and from above; numbered segments indicate the three levels shown in craniocaudal succession; X 3.3. Figs. 4b to 4d, the same reconstruction viewed similarly (fenestral portion shown); intact (Fig. 4b), and after removal of the first segment (Fig. 4c) and the second segment (Fig. 4d) to show, respectively, the area of origin of the cul de sac of the scala tympani, the scala tympani at a level between the cul de sac and the periotic duct, and the area of origin of the latter diverticulum; X 8.25. In Fig. 4b the lower arrow passes into the posterior semicircular canal, the upper arrow, into the lateral canal. Figs. 4e and 4f, the entire reconstruction viewed from the tympanic aspect, and turned so as to show, respectively, the relation of the cartilage bar to the periotic duct and of the cul de sac of the scala tympani to the developing roof of the fossula of the cochlear fenestra; X 8.25.

At this crucial stage the wall of the aditus to the fossula has been ossified through three-fourths of its circumference (Figs. 4b to 4d); the unossified portion, situated caudally, is formed by the cartilage bar (Figs. 4e and 4f). The growing bar of cartilage, in its upward-directed course, has reached the level at which the scala tympani gives off the periotic duct (Figs. 4c and 4d). The bar now forms the lower margin of the fenestra Fig. 4e, at 1) and has fused with the promontory (Fig. 4e, at 2); however, it has not yet spread far enough to meet the medial rim of the fenestra (Fig. 4e, at 3). Thus, the periotic duct, which lies in the meningeal portion of the hiatus, is still visible from the tympanic side (Figs. 4e and 4f). The osseous spiral laminae have not yet appeared (Figs. 4a and 4b), nor have they in the succeeding stage (167-mm fetus, Fig. 5). The scala tympani, together with the derived cul de sac and the periotic duct, are seen from the fossula of the cochlear fenestra. The cul de sac extends across the cupula of the fossula (Figs. 4b and 4f); the periotic duct descends toward the cranial cavity (Fig. 4d and 4e). Neither the canaliculus (aqueduct) for the periotic duct nor the osseous channel for the cochlear vein is yet formed.

by the cartilage bar (Figs. 5b and 5c). The next, and third, crucial step in the morphogenesis of the latter element is represented by the fusion of the cartilage with that portion of the capsule which forms the posteromedial rim of the cochlear fenestra (Fig. 5c, at 3). This fusion virtually completes the separation of the tympanic and meningeal division of the original gap, since fusion has already occurred anteriorly (Fig. 5b, at 2). The irregular remnant of this hiatus is obliterated in the succeeding stage of development by the further growth of membrane bone (compare Fig. 2c, at 4), which serves to produce independent channels for transmission of the periotic duct and the cochlear vein. The tympanic division of the gap contains the fossula of the cochlear fenestra and the secondary tympanic membrane, whereas the meningeal division contains the periotic duct.

Because the osseous spiral laminae are not yet formed (future sites at small arrows in Fig. 5a), the roof, or dome, of the fossula is still membranous; the cul de sac of the scala tympani projects into the membranous roof (Figs. 5a to 5c) between the horizontal segment of the secondary tympanic membrane and the arch of the scala media.

The cul de sac of the tympanic scala occupies the summit of the fossula. In forming the floor, or inferior boundary, of the cul de sac, the secondary tympanic membrane assumes an arch-like form, concave toward the fossula, convex toward the scala (compare Figs. 6b and 6c).

183-*mm Fetus*

In the fetus of 183 mm (21 weeks) the rim of the cochlear fenestra (crista fenestrae cochleae) is largely formed in bone; cartilage persists along its lower border. This remnant of the cartilage bar, spatulate in form in its upper reaches, merges with the developing bone of the crest of the cochlear fenestra. By further spread of bone, it will become completely ossified. Growth of membrane bone has resulted in the formation of separate bony channels for the periotic duct and the vein.

The fossula of the cochlear fenestra is still nonpneumatized.

215-*mm Fetus*

In the fetus of 215 mm (24½ weeks) the wall of the fossula is now composed of periosteal bone (Fig. 2d); the space thus enclosed

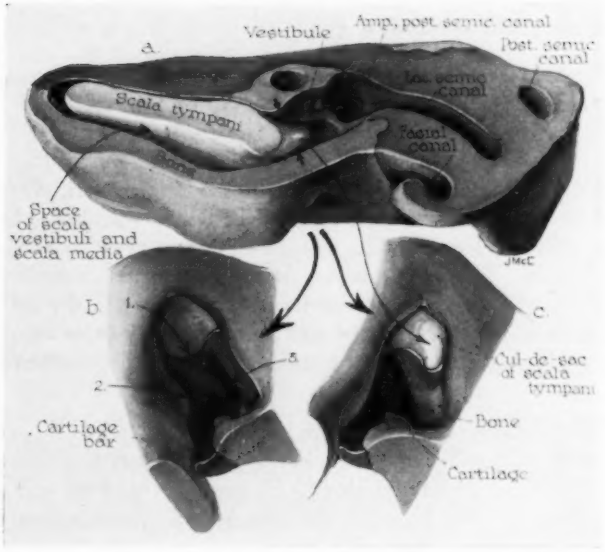


Fig. 5a to 5c.—Drawings of a reconstruction of a segment of the otic capsule, to include the fossula of the cochlea fenestra, in a fetus of 20 weeks (167 mm); Wis. ser. 105. Fig. 5a, the entire reconstruction, seen as if from the side of the head and from above. In the vestibular and canalicular regions the periotic (perilymphatic) canals are shown as spaces; in the cochlear region the scala tympani, with its cul de sac, is modelled as a solid; X 6. Epithelial (otic, endolymphatic) ducts are not included. Were the scala media included in the reconstruction, it would lie upon, that is, superior to, the cul de sac of the scala tympani. Figs. 5b and 5c, the fossular region of the same reconstruction enlarged, the model seen from below and, respectively, toward the canalicular and cochlear portions of the wall of the fossula; X 12. The secondary tympanic membrane is omitted.

Ossification has already spread to the medial wall of the canalicular division of the otic capsule (lighter area), to the lateral wall of the cochlear division and the vestibule (Fig. 5a), and to the internal acoustic meatus (toward which an arrow passes from the ampulla of the posterior semicircular canal). Both bone and cartilage contribute to the formation of the walls of the fossula, and to the rim of the cochlear window. The cartilage bar has ascended to form the floor of the cochlear window (Fig. 5b, at 1) and has broadened to close the inferior two-thirds of the once capacious tympanomeningeal hiatus by fusing with the walls of the fossula (Fig. 5b, at 2 and 3). The cul de sac of the scala tympani occupies the summit of the fossula of the cochlear fenestra. The osseous spiral laminae are just appearing (at small arrows in Fig. 5a).

is pneumatized through two-thirds of its depth. Some of the cartilage of the original chondral bar remains near the free edge of the osseous crest of the cochlear window (Fig. 2d).

Membrane bone now intervenes between the cul de sac of the scala tympani and the arch and cul de sac of the scala media (Fig. 2d, at 4), either as the osseous spiral laminae (Fig. 2d, at I and II) or as the laminae merged to produce a single undivided plate (compare Fig. 2e). The roof of the cul de sac of the scala tympani is formed by the osseous laminae and by the basilar membrane between the tips of these ledges. The osseous laminae serve also as the roof of the fossula. The cul de sac of the scala tympani, at its distal extremity, extends to the posterior limit of the fossula; the cul de sac of the scala media lies internal to the fused portions of the osseous laminae, within the space of the cochlear recess of the vestibule (Fig. 2d).

The formation of the osseous spiral laminae progresses concurrently with thickening of the periosteal layer and with ossification of the rim of the cochlear window. However, as pointed out earlier, the middle and inner layers of the capsule still remain quiescent, the former being sparse, the latter continuing as a thin stratum (Fig. 2d).

305-*mm Fetus*

Even in the fetus of 305 mm (34 weeks), a nodular remnant of the cartilage bar persists within the osseous rim of the cochlear fenestra. However, the crest of the cochlear window (which supports the secondary tympanic membrane) is completely formed in bone.

The middle layer of the capsular wall has not yet attained petrous texture; the islands of intrachondrial bone have become invested by endochondral bone, yet the total bulk of the bony spicules does not exceed that of the marrow space by which they are surrounded (compare newborn, Fig. 2e).

The secondary osseous spiral lamina forms a definite support for that part of the spiral ligament which extends into the vestibule, and constitutes part of the wall of the cul de sac of the scala tympani.

The secondary tympanic membrane has attained a heavily fibrous character, and the fossula is lined by mucous membrane continuous

with that of the tympanic cavity. Near the cupula-like summit of the fossula, the membrane changes plane from the vertical to the horizontal, its line of fixation shifting posteriorly along the dome of the fossula. Consequently, attachment is made to the basal portions of the osseous spiral laminae (as in the newborn, Fig. 2e).

Pneumatization of the fossula of the cochlear fenestra has progressed to the point at which the fossula itself, the fenestra and the secondary tympanic membrane are established in substantially adult form.

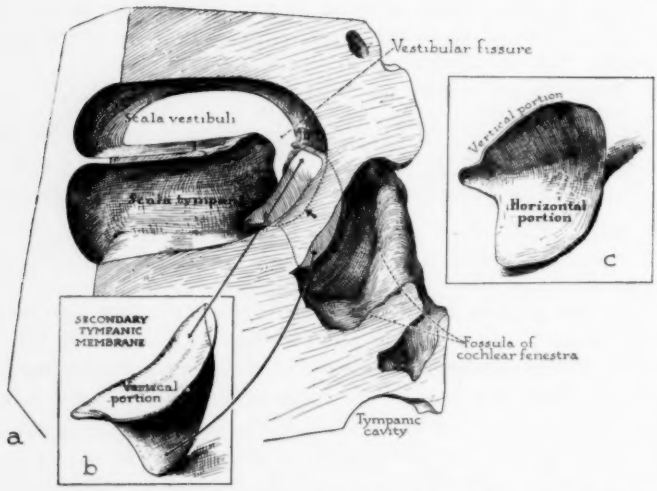
Newborn

The otic capsule of the newborn specimen (Fig. 2e) is but slightly advanced over that of the 305-mm fetus. In the former, a single notable advance is apparent in the complete disappearance of cartilage from the crest of the cochlear window. At the infero-medial border of the cochlear window the periotic duct leaves the scala tympani to occupy a channel in bone near the osseous canal for the cochlear vein. Curiously, in the presence of these features which suggest maturity of structure, the capsule itself retains a fetal appearance in its middle layer; therein little production of endochondral bone has taken place, and primitive marrow is still abundant.

The osseous spiral laminae, as seen in sections, present an adult appearance. Where the laminae are separate, they, together with the basilar membrane, intervene between the cul de sac of the scala tympani and the arch of the scala media; where conjoined, the common osseous partition completely separates the vestibule from the fossula (Fig. 2e). The cul de sac of the scala tympani has as its floor, or inferior boundary, the secondary tympanic membrane; the arching membrane is at the same time the roof, or superior boundary, of the fossula of the cochlear fenestra (the latter is sectioned in Fig. 2e across its cupola). The cul de sac of the scala media occupies the antero-inferior portion of the vestibule.

Infant and Adult

In the infant the capsule has attained petrous character through late, but rapid, production of endochondral bone; structurally, the capsule is like that of the adult (Fig. 2f). The spread of endochondral bone has resulted in the virtual obliteration of marrow spaces. The intrachondrial bone, however, remains a readily recog-



Figs. 6a to 6c.—Temporal bone in the region of the cochlear fenestra. Adult of 19 years. Wis. ser. B 124. Drawings of a reconstruction of a segment of the temporal bone in the region of the fossula, fenestrae and periotic duct, and of a paper model of the secondary tympanic membrane. X 16.

In the ear of the adult (Fig. 6a) the following features are noteworthy: separation of the tympanic and vestibular scalae (except along the vestibular fissure) by the osseous spiral laminae (at I and II); attachment of the secondary tympanic membrane along its vertical portion to the circumference of the cochlear window (as at the unlabelled arrow) and along its horizontal part to the roof of the fossula; separation of the fossula of the cochlear fenestra from the scala tympani by the secondary tympanic membrane, but continuity of the fossula with the middle ear through the aditus; the arched form of the secondary tympanic membrane.

nizable histological feature; the presence of this bone, together with the associted vascular canals, serves to record the boundaries of the middle layer, and thus to render this central stratum permanently distinguishable from the outer and inner layers.

In its vertical portion, the secondary tympanic membrane is attached to the external, or tympanic, aspect of the sharp osseous ridge of the cochlear window (Fig. 2f). However, in the horizontal, or arching, portion the border is fixed to basal portions of the osseous

spiral laminae. The membrane assumes the form of a strong, yet thin, diaphragm on whose fossular, or tympanic, surface a mucosal contribution is no longer distinguishable at medium magnification.

In recent textbooks and journal articles the region of the cochlear fenestra has not been critically considered. Frequently, in viewing the area from the external auditory meatus, the tympanic opening of the sac-like recess, the fossula of the cochlear fenestra, which leads to the window, has been regarded as the window itself. Actually, the cochlear fenestra is hidden from view in the anterosuperior part of the fossular pocket, so that even from the most favorable viewpoint only a very small part of it can be seen from the middle ear, and no part of it is in view from the external auditory meatus.*

In the adult, *the fossula of the cochlear window* (fossula fenestrae cochleae, fossula fenestrae triquetrae, canaliculus fenestrae rotundae or niche of the cochlear window), is an irregularly prismatic recess, with rounded angles, which extends from a point near the bottom of the middle ear upward and inward beneath the arch of the first turn of the cochlea. One surface of the prism-shaped space is directed downward and represents the tympanic aditus of the fossula (Figs. 6a, 7a and 7d). Much of the rim of this opening is formed by the overhanging ledge of the promontory produced by the arch of the first coil of the cochlea. In a macerated temporal bone, the roof of the fossula fenestrae cochleae is formed by the osseous spiral laminae (compare Fig. 7a).

These two osseous spiral laminae, at their vestibular extremities, therefore, form the roof of the fossula of the cochlear fenestra (Figs. 7a and 8a). The *osseous spiral lamina* (lamina spiralis ossea) is a thin, flat ledge of bone which winds around the modiolus of the cochlea like the thread of a screw; the lamina projects about halfway into the cochlear tube, thus incompletely dividing it into two bony passages—one for the scala vestibuli and scala media, the other for the scala tympani. In the lower half of the basal coil, a smaller, more delicate bony plate, termed the *secondary osseous spiral lamina* (lamina spiralis ossea secondaria) projects from the outer wall of the

*In the older literature on the fossula, cochlear window, and secondary tympanic membrane, more accurate accounts were given. Foremost are the accounts of Scarpa (1772),[15] Siebenmann (1897)[16] and of Denker and Kahler (1926).[14] The 1916 edition of Cunningham's Textbook of Anatomy[13] gives a good description of the form of the secondary tympanic membrane, but in the recent editions of the same textbook, such information is omitted.

cochlea toward the osseous spiral lamina, without, however, reaching it. As a result, over the greater part of the roof of the fossula the free edges of these laminae face each other but do not meet; as a consequence, a slit-like vestibular fissure through the greater part of their course along the arch of the basal cochlear coil (Figs. 6a, 7a and 8a). The laminae are continuous with each other at their vestibular extremities (Fig. 8a, at *). The basilar membrane, which separates the scala tympani from the scala media, crosses the fissure between the two laminae (compare Fig. 9).

Interposed between the tympanic and vestibular scalae is the *cochlear duct* (ductus cochlearis, scala media), for which the basilar membrane forms one of the three walls (Figs. 8c, 8d and 9). Where the two bony laminae fuse at their vestibular extremities, there occurs a shallow depression, the *cochlear recess* (recessus cochlearis), which houses the cul de sac of the scala media (Fig. 8a, at *).

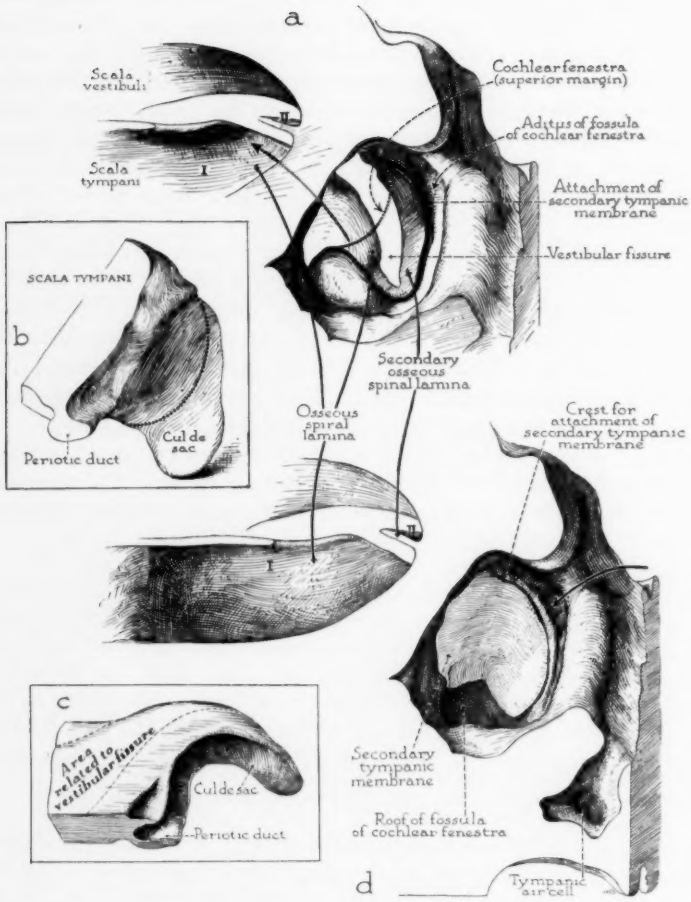
The *cochlear fenestra* (fenestra cochleae, fenestra rotunda, or round window) of the adult temporal bone lies in the anterosuperior wall of the fossula (Figs. 7a and 7d). Its bony margin is formed posteriorly by part of the cochlear capsule, inferiorly by the bone which developed in late fetal life from a bar cartilage, anteriorly by part of the inner portion of the bony promontory, and superiorly by the two bony spiral laminae. Superiorly its bony rim, between the opposing edges of the bony spiral laminae, is incomplete, so that the window is continuous with the vestibular fissure (Figs. 7a and 8a). From the tympanic cavity (tympanum, or middle ear) the fenestra is reached through a funnel-shaped recess, the fossula of the cochlear fenestra (Fig. 7d, along course of arrow), by whose overhanging ledge the window is almost hidden from view. The fenestra itself is somewhat irregular in outline. In a macerated specimen the window opens into the cochlea; in the fresh state it is closed by the secondary tympanic membrane (Figs. 6a to 6c, 7d and 8e).

The *secondary tympanic membrane* (membrane secondaria tympanica), which closes the cochlear fenestra, consists of three layers: a lateral layer, continuous with the mucosal epithelium of the tympanic cavity; an intermediate fibrous layer, which is continuous with the mucoperiosteum; a medial layer, continuous with the scant periotic tissue which lines the labyrinth. The lateral and intermediate layers of the membrane are those strata, continuous with the mucoperiosteum of the middle ear, which do not cover bone, but border the scala tym-

pani by whose epithelium it is lined. The margin of this membrane does not entirely follow the rim of the bony round window. Its complete circumference is attached to a more or less prominent ridge of bone (Fig. 2f). This ridge, in its upper part, markedly deviates from the course of the rim of the round window (Fig. 7a, at solid and broken lines, respectively. In its lower two-thirds, where it corresponds essentially to the rim of the bony round window, this ridge is known as the semilunar crest (crista semilunaris). In its upper third the membrane bends away from the osseous window at almost a right angle; it curves posteriorly below the arch of the spiral laminae to form the roof of the fossula, where it is attached to a less prominent ridge (Figs. 6a, 7a and 7d). The lateral part of the ridge, or crista, is at the base of the secondary bony spiral lamina, and the medial part at the base of the primary bony spiral lamina. These two parts of the ridge meet at a blunt angle where the two bony spiral laminae join. In its lower two-thirds the secondary tympanic membrane is rounded and lies in a vertical plane, but its upper third inclines posteriorly as a triangular arching membrane, which forms part of the dome of the fossula (Figs. 6b, 6c, 7d and 8e). Between this arching triangular part of the membrane and arciform spiral lamina lies a blind, arch-like, dorsoventrally compressed projection of the scala tympani, the cul de sac of the scala tympani (Figs. 7b, 7c and 8b).

Close to the fenestral extremity of the scala tympani, and on its inferomedial wall, is seen the internal orifice of the *cochlear aqueduct* (canaliculus cochleae, cochlear canaliculus); this minute channel, 10 to 12 mm in length in the adult ear, opens on the under surface of the petrous part of the temporal bone in the upper border of the jugular fossa. The osseous channel transmits the *periotic duct* (ductus perilymphaticus, perilymphatic duct) which brings the space of the scala tympani into communication with arachnoid tissue.

The arching form of the superior portion of the secondary tympanic membrane accounts for the concavity of the cul de sac of the scala tympani, as it does likewise for the cupola-like form of the fossula (Figs. 6a and 7d). Just as the scala tympani, in being prolonged beneath the osseous spiral laminae, extends into the fossula of the cochlear fenestra, so the scala media (cochlear duct), through extension above the laminae, is carried as a cul de sac into the vestibule (Figs. 8a, 8c, 8d and 9). The scala media, narrower than the scala tympani, is carried over the osseous spiral laminae in arching


a
Scala vestibuli
Scala tympani
I
II
Cochlear fenestra (superior margin)
Aditus of fossula of cochlear fenestra
Attachment of secondary tympanic membrane
Vestibular fissure
Secondary osseous spiral lamina
Osseous spiral lamina
SCALA TYMPANI
b
Cul de sac
Perilymphatic duct
Crest for attachment of secondary tympanic membrane
c
Area related to vestibular fissure
Cul de sac
Perilymphatic duct
Secondary tympanic membrane
Roof of fossula of cochlear fenestra
d
Tympanic air cell

Figs. 7a to 7d.—Otic capsule in the region of the cochlear fenestra. Same specimen. Drawings of reconstructions of the otic capsule, scala tympani and secondary tympanic membrane. X 16. Fig. 7a, the reconstruction, viewed from the inferior aspect. Figs. 7b and 7c, a reconstruction of the scala tympani, viewed from below and from the side, respectively. Fig. 7d, the reconstruction of the fossular and related spaces and structures, viewed from below, with the secondary tympanic membrane *in situ*.

The secondary tympanic membrane forms the roof of the fossula of cochlear window (Fig. 7d), its attachment (Fig. 7a, along heavy, unbroken line) departing superiorly from the circumferential rim of the round window (Fig. 7a, along broken line). Between the fenestral rim and the line of anchorage of the membrane the scala tympani is prolonged superiorly as a cul de sac (Fig. 7b).

Were the cast of the space of the scala (Fig. 7b) placed in natural position in the reconstruction of the fossular region (Fig. 7a) it would occupy the space between the line of attachment of the secondary tympanic membrane (Fig. 7a) and the osseous spiral laminae (Fig. 7a, at I and II); in the area between the free edges of the laminae, the scala is related to the vestibular fissure (Fig. 7c), the latter cleft being closed in the natural state by the basilar membrane. The secondary tympanic membrane (shown as if in normal position in Fig. 7d) forms the superior boundary of the fossula of the cochlear fenestra. The fossula communicates with the tympanic cavity through the aditus (along the course of the arrow in Fig. 7d). (After Bast and Anson: Quarterly Bulletin of Northwestern University Medical School, 26:344-373, 1952.[12]

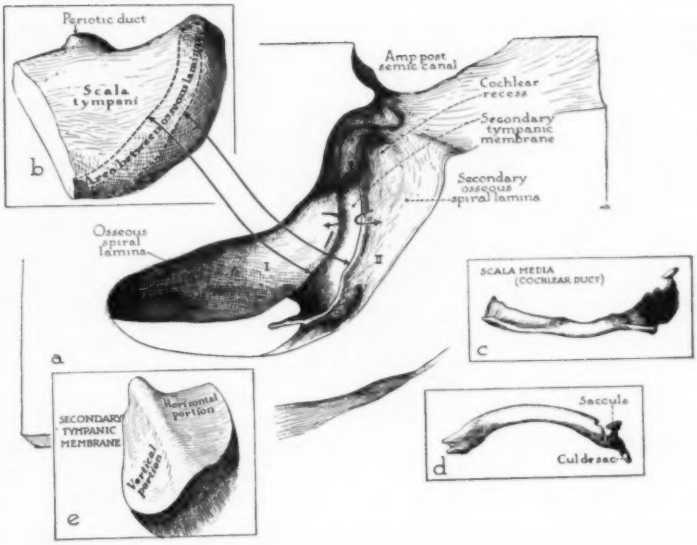
form (Fig. 8a, at broken lines). The cul de sac is continuous with the ductus reuniens, the latter, in turn, with the saccule (Figs. 8c and 8d).

CONCLUSIONS

In the region of the future cochlear fenestra of the otic capsule of the human ear, prior to ossification, a capacious, mesenchyma-filled gap, the tympanomeningeal hiatus, partially separates the canalicular and cochlear divisions. This interval in the chondral capsule of the 9-week (40-mm) fetus passes from the future tympanic cavity to the cranial cavity; the mesenchyma which fills it is continuous on the tympanic aspect with tissue which will become a submucosal layer, and on the cranial surface with the developing meninges. The glossopharyngeal nerve is situated at the cranial extremity of this wide gap; the inferior petrosal sinus is located internally; anteriorly appear the vestibular extremity of the scala tympani, the perilymphatic duct and the vein of the cochlea. The tympanic subdivision of this area eventually becomes pneumatized to form the fossula of the cochlear fenestra.

In the fetus of 10 weeks (50 mm) the initial step has been taken toward ultimate segregation of the perilymphatic duct, cochlear vein and formation of the secondary tympanic membrane; a cartilage bar already intervenes between the glossopharyngeal nerve and general glossopharyngeal nerve in individual osseous channels, and toward space of the hiatus.

In fetuses of 11 weeks (62 mm) and 12 weeks (84 mm), the change just described is progressively advanced, without dramatic alteration in the structure or position of the formative elements. However, in the 16-week (126-mm) stage, considerable advancement has been made toward the attainment of definitive form of the cochlear fenestra and the fossula, and toward the adult conformation of the secondary tympanic membrane. So striking are these changes, that together they may be regarded as constituting an important phase in morphogenesis of the fenestro-fossular region of the otic capsule. The changes may be enumerated, as follows: (a) formation of ossification centers has been carried to a stage at which, in all but the inferior and anterior part of the aditus to the fossula of the cochlear fenestra, cartilage has been replaced by bone; (b) the unossified antero-inferior quarter of the margin of the cochlear fenestra



Figs. 8a to 8e.—Otic capsule in the region of the cochlear fenestra, and in relation to portions of the scala tympani and scala media. Same specimen (adult of 19 years). Drawings of reconstructions. Figs. 8a, 8b and 8e, X 66; Figs. 8c and 8d, X 33. Fig. 8a, the reconstruction of the fossular region seen from above (superior aspect). Fig. 8b, the reconstruction of the scala tympani, seen from above. Figs. 8c and 8d, a reconstruction in the form of a cast, of the proximal segment of the scala media, viewed from above and from the side, respectively. Fig. 8e, model of the secondary tympanic membrane viewed from a superolateral position.

The osseous spiral laminae (Fig. 8a, at I and II) in the region of the cochlear window form the supporting floor for the scala vestibuli and the scala media (Figs. 8c and 8d). In the natural state the scala media would lie cranial to the vestibular fissure and rest upon the portions of the laminae (between the straight lines in Fig. 8a); the cul de sac of the scala media (Fig. 8d) would be lodged in the vestibular recess (Fig. 8a, at *) formed by conjoined laminae. The scala tympani (into which, in Fig. 8a, the curved arrows pass) would have as its roof the osseous spiral laminae and the basilar membrane between the facing edges of the laminae (the latter area indicated in Fig. 8b). The scala tympani is prolonged toward the vestibule as the cul de sac and into the cochlear canaliculus as the periotic (perilymphatic)duct (Fig. 8b). The secondary tympanic membrane (Fig. 8e) forms the floor of the scala tympani proper and of its extension. The arciform character of the membrane (Fig. 8e) accounts for the concave form of the caudad aspect of the scala tympani (Figs. 7b and 7c).

is made up of the cartilage bar, which has ascended in a curving course to lie on the fossular surface of the ossifying rim of the cochlear window; (c) the scala tympani, in sending a prolongation, or cul de sac, in the direction of the vestibule, has come to occupy the cupola-like superior area of the fossula of the cochlear fenestra—and thus to be separated from the fossular bay of the future tympanic cavity only by the secondary tympanic membrane; (d) the membrane, although not yet of adult histological structure, has attained adult form in being carried like an arching canopy, in its cranial third, from a vertical to a generally horizontal plane—its line of peripheral anchorage departing superiorly from the margin of the cochlear fenestra. As for the otic duct system, it may be said that the scala media already possesses a prolongation, or cul de sac, which arches over that of the scala tympani, extending into the vestibule; it is there continuous with the ductus reuniens.

In the fetus of 20 weeks (167 mm), the expanding cartilage bar has been partly converted into bone; the invading mucous membrane approaches the tympanic orifice of the fossula of the cochlear window; the bone of the developing crista of the cochlear fenestra, while now adjacent to the periotic duct and cochlear vein, has not yet spread to form channels for the duct and vessel.

Formation, in membrane bone, of the cochlear aqueduct for the periotic duct and a neighboring osseous canal for the vein of the cochlea, marks another definitive step in capsular development in the region of the cochlear fenestra. These advances are evidenced in the 21-week (183-mm) fetus; they are accompanied by proportionate increase in bone of the crista of the cochlear window.

In the fetus of 24 weeks (215 mm), a fourth advance in morphogenesis is noted in the presence of the osseous spiral laminae; they were represented by preosseous ledges in the 21-week stage. Now formed in membrane bone, as are the crista and the aqueduct, the laminae project toward each other from facing walls of the cochlear canal. Through the greater part of their extent in the region herein discussed, they appear as incomplete partitions between the cul de sac of the scala tympani and the corresponding prolongation of the scala media—the basilar membrane closing the interval between the free edges of the laminae. Nearer the vestibule, where the laminae meet at their tips to form a complete osseous septum between the vestibule and the fossula, the combined plate becomes foveate on its superior

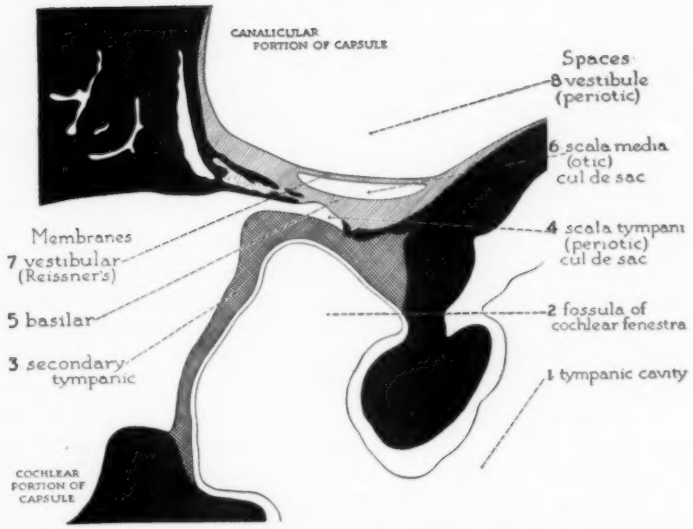


Fig. 9.—Succession of spaces and limiting membranes from the middle ear through the chambers of the otic (endolymphatic) and periotic (perilymphatic) labyrinthine systems of the inner ear. Schematized from a transverse section through the temporal bone of a 6-month infant, Wis. ser. 121, sl. 9, sect. 4.

The following spaces and structures are encountered: tympanic cavity (at 1); fossula of the cochlear fenestra (2); secondary tympanic membrane (3), closing the cochlear fenestra (round window) and anchored to a circumferential crista; cul de sac (or caecum) of the scala tympani (4); basilar membrane (5), supported by the osseous spiral laminae and bridging the vestibular fissure; cul de sac of the scala media (6); vestibular (Reissner's) membrane (7); vestibule (8).

surface to form the cochlear recess for reception of the cul de sac of the scala media.

All further phases in development represent continuations of processes already under way in the fetus of 34 weeks (305 mm), or in antecedent stages. Among these, the most striking advances toward maturity in form and structure are the following: ossification of the crista of the cochlear fenestra except in a small area of the free margin, where a mere nodule of cartilage persists; spread of mucous

membrane from the tympanic cavity, to pneumatize the fossula of the cochlear fenestra completely, and by application to the external surface of the fibrous secondary tympanic membrane, to become a histologically integral part of that diaphragmatic plate; complete ossification of the walls of the fossula, save for characteristic tardiness in the production of endochondral bone in the middle one of the three capsular laminae.

The production of the full, mature, quota of endochondral bone in the middle layer marks the termination of development of the otic capsule in the region of the cochlear fenestra and its fossula. This closing phase of morphogenesis is not special to the fenestral area; rather, it is a phase which effects the entire capsule, although not concurrently in its several divisions. Since the process is completed in early postnatal months, the fossular and fenestral regions appear quite similar in the term fetus, the infant and the adult. This equivalent to saying that, except for immaturity of the middle layer of the capsule in the fetus of approximately 30 weeks, that stage represents adulthood in the form of the structures and areas to the consideration of which this report has been chiefly devoted. Early attainment of, or approach to, maturity is, therefore, characteristic of all portions of the otic capsule thus far investigated by the present authors and their colleagues, as was also found to apply in their study of the auditory ossicles and of the membranous labyrinth.

The adult form and plane of the cochlear window are such that neither the fenestral opening nor the secondary tympanic membrane would be visible from the external acoustic meatus—the fenestra being situated in the depths of a prism-shaped fossula (entered from the tympanic cavity through an aditus) and disposed in a plane, in its lower portion, which is at a right angle to that of the tympanic orifice of the meatus.

The secondary tympanic membrane, in its lower two-thirds, follows the line of the cochlear fenestra, being, therefore, disposed in vertical plan. However, in its upper one-third the membrane turns horizontally, that is, away from the fenestra at a right angle. This means that the superior segment of the membrane forms the roof (cranial boundary) of the fossula of the cochlear fenestra and, at the same time, constitutes the floor (caudal boundary) of the cul de sac of the scala tympani. Next in succession, in passing to a still higher level, is situated the cul de sac of the scala media—as it

conforms to the arching configuration of the subjacent prolongation of the scala tympani.

The above-described relationship between the fossula and the scala media lends attraction to Scarpa's theory, propounded long ago, to the effect that delicate or high-pitched sounds, too weak to activate the ossicular chain, might stimulate the scala media (cochlear duct) directly through the cochlear window.

It is also important to note that the relationship just described renders the labyrinth vulnerable in the probing or sponging of the fossular space from the ear. Failure to exercise caution might easily result in perforation of the secondary tympanic membrane and of the portions of the periotic (perilymphatic) and otic (endolymphatic) spaces which lie superior to the membrane.

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XCV

NYSTAGMUS AS A SIGN OF CENTRAL NERVOUS SYSTEM INVOLVEMENT

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The conditions producing nystagmus and the various factors which increase or modify it or which prevent its appearance are of common interest to the neuroanatomist and the otologist. Such nystagmus may be peripheral or central in origin. The present report will deal with some of the anatomic connections and relations which underlie the centrally produced type.

The individual, sitting or standing erect, is constantly shifting slightly the position of his head and body. Impulses are passing then continually over the vestibular arcs, with the balance in favor of first one vestibular area and then the other. Consequently there are almost constant, very fine to-and-fro, or up-and-down, movements of the eyes, except when they are fixed definitely upon an object. These movements are usually so slight as to pass unnoticed. Nevertheless, they have been studied carefully by Marx and Trendelenburg (Kestenbaum[11]). They represent a vestibular reflex and depend upon the secondary vestibular connections within the central nervous system. When they are exaggerated due to an increase in the imbalance between the vestibular areas of the two sides, they become a vestibular nystagmus. Strangely enough, although their presence in the normal individual is usually unnoticed, their absence gives a continuously fixed, staring quality to the gaze which is startling.

Impulses set up in the peripheral vestibular apparatus are projected over vestibular nerve fibers, with their cells of origin in the vestibular ganglia, to the vestibular centers of the brainstem—the lateral, medial, superior and inferior vestibular nuclei—and directly to the cerebellum (Spiegel and Sommer,[17] Grinker and Bucy,[10] and others). From each medial vestibular nucleus (Spitzer,[18] Rasmussen,[14] and others) and from the more caudal half of each lateral vestibular nucleus (Buchanan,[1] cat; also front end of inferior vestibular nucleus), impulses

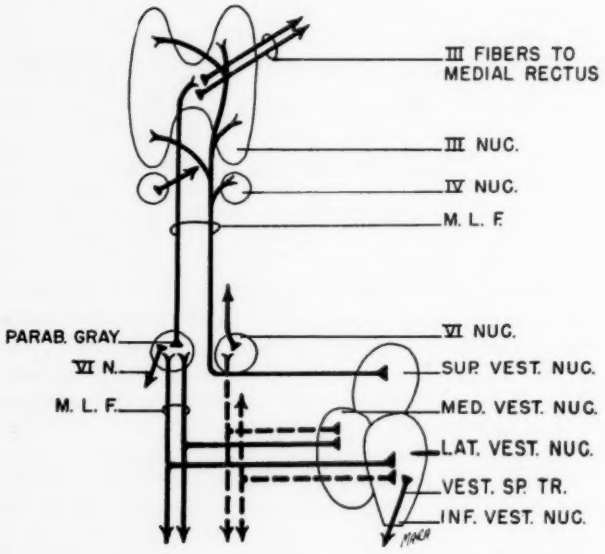

Fig. 1.—A diagram showing certain connections of the vestibular centers with the eye muscle nuclei. INF. VEST. NUC., inferior vestibular nucleus; LAT. VEST. NUC., lateral vestibular nucleus; M. L. F., medial longitudinal fasciculus; MED. VEST. NUC., medial vestibular nucleus; PARAB. GRAY, parabducens gray or nucleus; SUP. VEST. NUC., superior vestibular nucleus; VEST. SP. TR., ventrolateral vestibulo-spinal tract; III NUC., oculomotor nucleus; IV NUC., trochlear nucleus; VI N., abducens nerve; VI NUC., abducens nucleus.

are relayed across the midline and then forward over the medial longitudinal fasciculus to the abducens nucleus (Fig. 1). From cells of reticular type (often termed collectively the parabducens nucleus, Strong and Elwyn[19]) in the region of the abducens nucleus, fibers are projected over the medial longitudinal fasciculus (of the same side, Spiegel and Sommer[17] and Crosby,[4] of other side, Cogan, Kubik, and Smith[2]) forward to those portions of the oculomotor nucleus (Fig. 1) supplying the contralateral medial rectus muscle, so that simultaneous contraction of the lateral rectus of one eye and the medial rectus of the other may be accomplished. Thus conjugate deviation of the eyes in the horizontal plane becomes possible. A

smaller number of fibers (Fig. 1) from these vestibular nuclei ascend, without crossing, in the medial longitudinal fasciculus to the ipsilateral abducens and parabducens nuclei (Rasmussen[14]), with the parabducens nucleus again relaying impulses forward to appropriate portions of the oculomotor complex. It is believed that such uncrossed fibers may be concerned with relaxation of the antagonistic muscles, and that this relaxation is provided for by inhibiting or reducing the flow of impulses over the related peripheral nerves.

From each lateral vestibular nucleus, fibers descend to the motor centers of the spinal cord by the ventrolateral vestibulo-spinal tract (Fig. 1), to set off reflexes for maintaining body equilibrium. A destruction of the lateral vestibular nucleus will produce a falling away from the side of the lesion (if the inferior cerebellar peduncle or the entering vestibular root fibers are not involved). From the superior vestibular nucleus (Rasmussen[14]) on each side impulses are projected forward, over the homolateral medial longitudinal fasciculus, to the trochlear and oculomotor nuclei. Such connections are concerned with vertical and oblique deviations of the eyes. All the above vestibular connections have been proved experimentally.

Irritative lesions involving the lower part of the lateral and the medial vestibular nuclei will produce a nystagmus with its quick component toward the side of the lesion. Irritative lesions in the superior vestibular nucleus, and probably including also the upper part of the lateral, are indicated by vertical or oblique nystagmus. Rotatory or irregular types of nystagmus suggest a considerable involvement of the vestibular area of one side. The nystagmus in all these instances is due to an imbalance between the discharge of the vestibular centers on the two sides of the brainstem.

The fact that nystagmus is being elicited from a central vestibular rather than a peripheral lesion is determined by noting the accompanying signs or symptoms. For example, the vertical nystagmus elicitable from either superior vestibular nucleus may be accompanied by a facial weakness since the facial root passes along the medial side of this nucleus as it descends toward its level of emergence from the brain; or by loss of sweating on the same side of the face since the brain tract, the lateral reticulo-spinal tract, related to such sweating lies not far ventral to the superior vestibular nucleus. With involvements of the lateral vestibular nucleus producing destruction of the ventrolateral vestibulo-spinal tract, the patient will fall away

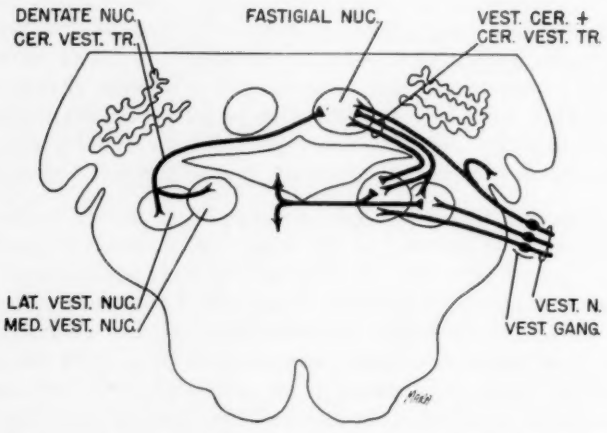

Fig. 2.—A diagram showing certain cerebello-vestibular interrelations of the cerebellum and the vestibular centers. CER. VEST. TR., cerebello-vestibular tract; DENTATE NUC., dentate nucleus; FASTIGIAL NUC., fastigial nucleus; LAT. VEST. NUC., lateral vestibular nucleus; MED. VEST. NUC., medial vestibular nucleus; VEST. CER. TR., vestibulo-cerebellar tract; VEST. GANG., vestibular ganglion; VEST. N., vestibular nerve.

from the side of the lesion, although in section of the vestibular root he falls toward the side of the lesion.

Not only does the cerebellum receive direct vestibular root fibers but it is also interconnected with the secondary vestibular centers. Vestibulo-cerebellar (Fig. 2) fibers terminate in the flocculo-nodular lobe (Larsell[12]) and in the nucleus fastigius of the cerebellum on each side. Cerebello-vestibular fibers (Fig. 2) arising in each nucleus fastigius, and also in the anterior lobe of the cerebellum, pass to the lateral and medial vestibular nuclei (Marburg,[13] and others). The cerebellum apparently tends to stabilize the activity of the vestibular centers and to further the vestibular reflexes by increasing the discharge from the homolateral vestibular nuclei and decreasing that from the contralateral nuclei. Consequently if there is a lesion in the nucleus fastigius on one side, or if one inferior cerebellar peduncle, which carries the cerebello-vestibular interconnections, is destroyed

or its functions interfered with by a vascular involvement or by pressure, a cerebellar nystagmus appears when the eyes are turned and held away from the midline (Cranmer,[3] Schneider, Kahn and Crosby[15]). The direction of the quick component depends, again, on whether the lesion is irritative or destructive and consequently may shift during the course of the syndrome. Many lesions—such as tumors on the floor of the fourth ventricle, thrombosis of the posterior cerebellar artery and Ménière's syndrome—produce a central nystagmus due to incision of the vesibular areas (with or without the inferior cerebellar peduncle proper) in the lesion.

Thus far we have been dealing with nystagmoid movements in response to various kinds of stimuli of the vestibular system, but nystagmus may be initiated by other than vestibular stimuli. Thus an individual riding on a railroad train and watching the telegraph poles as they pass steadily in review develops what is known as an optokinetic nystagmus. His eyes will follow the retreating telephone poles slowly and then quickly come back to center. A series of such slow deviations and quick returns constitutes optokinetic nystagmus. Such optokinetic responses depend upon pathways through the occipital and preoccipital regions of the cortex. Short association fibers carry impulses from the visual areas of the cerebral cortex along the lips of the calcarine fissures to the occipital and preoccipital regions of the same hemisphere. Long ago Foerster[8, 9] showed that stimulation of the midlateral part of the human preoccipital area produces horizontal deviation of the eyes away from the side of the stimulation. The existence of regions concerned with vertical deviation of the eyes has received direct experimental proof (Crosby and Henderson[5]) and indirect confirmation for man from various clinical cases. From the portions of the occipital and preoccipital areas which have to do with vertical or obliquely vertical upward deviations of the eyes, discharge is made by way of cortico-tectal paths (Int. Cort. Tect. Tr., Fig. 3) to rostromedial portions of the superior colliculi (Crosby and Henderson[5]) where, after synapse, the impulses are shunted to appropriate portions of the oculomotor nuclei. From those parts of the preoccipital and occipital regions of the cerebral cortex concerned with downward or obliquely downward deviation of the eyes, cortico-tectal fibers discharge to the caudolateral parts of the superior colliculi. In a tumor of the pineal body there is pressure on the superior colliculi (Fig. 3A), beginning usually with the rostral end. As a result, the patient is unable to follow a finger above the horizontal

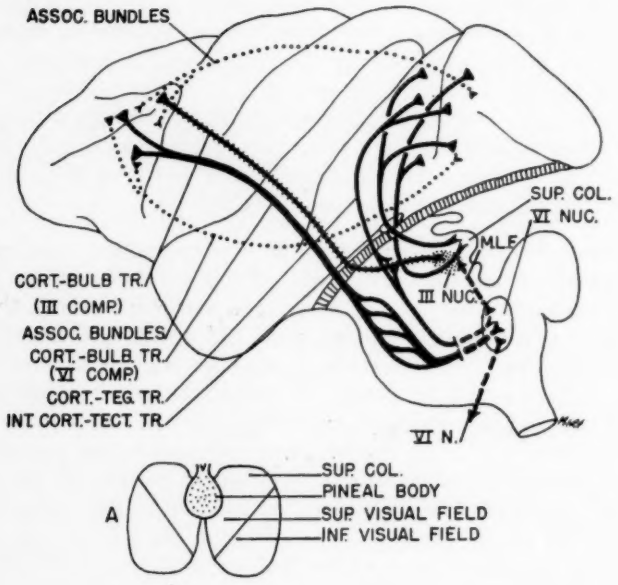

Fig. 3.—A diagram to illustrate the connections of the frontal and the preoccipital and occipital regions with the eye muscle nuclei. The small diagram shows the relations of the pineal body to the superior colliculi. ASSOC. BUNDLES, association bundles; CORT. BULB. TR. (III COMP.), cortico-bulbar tract, oculomotor component; CORT. BULB. TR. (VI COMP.), cortico-bulbar tract, abducens component; CORT. TEG. TR., cortico-tegmental tract; INF. VISUAL FIELD, inferior visual field; INT. CORT. TECT. TR., internal cortico-tectal tract; M. L. F., medial longitudinal fasciculus; SUP. COL., superior colliculus; SUP. VISUAL FIELD, superior visual field; III NUC., oculomotor nucleus; VI N., abducens nerve; VI NUC., abducens nucleus.

plane although he may look voluntarily in that direction. With later increase in size of the tumor—or in the rare cases where the tumor begins at the tip of a pineal body and presses first on the caudal regions of the superior colliculi—loss of the ability to follow a finger or a light downward or obliquely downward below the horizontal plane may appear.

From the portions of occipital and preoccipital fields, which, on stimulation, produce horizontal deviation of the eyes or horizontal nystagmus, cortico-tegmental pathways (Fig. 3) descend through the internal capsule and the brainstem to end on the contralateral abducens nucleus (Crosby and Henderson,[5] macaque) and perhaps also on the contralateral vestibular nuclei (Spiegel and Sommer;[17] see also Spiegel[16]). They do not traverse in their course, nor end in, the superior collicular region, so that patients with pinealomas have no defects in eye movements in the horizontal plane, although they may be unable to follow a moving finger above the horizontal plane, and sometimes below that plane.

The frontal eye centers of the cerebral cortex concerned with voluntary deviations of the eyes in various planes occupy the portions of the middle and inferior frontal gyri rostral to the precentral fissure and the corresponding regions in other primates. Cortico-bulbar components of the pyramidal system descend from these areas through the genu of the internal capsule to the brainstem. At midbrain and upper pons levels, those functionally related to horizontal deviation [Fig. 3, Cort. Bulb. Tr. (VI Comp.)] gradually turn off from the main pyramidal system to join the medial lemniscus—this constituting a part of the aberrant pyramidal system (Dejerine,[7] man; Crosby, Yoss and Henderson,[6] primates). As the lower one-third of pons is approached, the fibers decussate almost completely before terminating in the abducens and the parabducens nuclei. From the parabducens nucleus, impulses are relayed forward to those portions of the oculomotor nucleus concerned with innervating the contralateral medial rectus muscle. The cortico-bulbar fibers from the frontal eye fields concerned with raising the lids, with carrying out vertical and oblique eye deviations, and with convergence end in the oculomotor and trochlear nuclei directly at midbrain levels (Fig. 3, Cort. Bulb. Tr., IV Comp.).

Nystagmus sometimes appears in frontal lobe involvements. From the frontal regions of the cortex, the cortico-ponto-cerebellar

system projects impulses to the cerebellar hemispheres of both sides (Larsell[12]), although dominantly to the contralateral side, and to the cerebellar vermis, particularly to its contralateral portion. Among the regions in the vermis receiving such impulses are those overlying and connected with the nucleus fastigius. Irritative lesions, then, within the cerebral cortex upset the functions of the nucleus fastigius in stabilizing cerebellar reflexes and so produce a cerebellar type of nystagmus. Changes in personality and other signs of frontal lobe involvement help to place the lesion. As the irritation in the frontal lobe subsides, the nystagmus disappears along with other indications of frontal lobe involvement.

The following case history (presented with the permission of Dr. Edgar Kahn and to be reported in greater detail later in a Neurosurgery text) illustrates certain points just discussed.

The patient, an army officer, had been ill for about seven years, and under observation part of this time in a psychiatric unit. Aside from marked increase in intracranial pressure he showed no recognized neurological signs. On admission to University Hospital, Ann Arbor, during this last year, because of the marked intracranial pressure, a ventriculogram was made and a mass discovered in the fourth ventricle. Dr. Kahn removed a sarcoma from the midline region of the floor of the fourth ventricle. Following the operation the patient had lost all finer movements and all eye reflexes initiated by vestibular stimuli in all planes. He could turn the eyes upward and downward and converge, on command (Fig. 4), or follow a finger in these directions, indicating that the connections from the frontal and from the occipital and preoccipital regions of the cerebral cortex to midbrain levels were intact. However, he had lost all ability to turn the eyes to either side, on command, or to carry out following movements in the horizontal plane.

Obviously the lesion in the preceding case involved both medial longitudinal fasculi in the neighborhood of the abducens nuclei but spared these nuclei since there was no internal strabismus on either side. It had extended far enough forward to destroy the connections from the superior vestibular nuclei to the trochlear and oculomotor nuclei, and far enough caudad to include the connections from the medial and lateral vestibular nuclei to the abducens nuclei since vestibular reflexes in the horizontal plane are lost. With the loss of vestibular responses all fine to-and-fro and up-and-down movements characteristically seen in the eyes of normal individuals had disappeared. Such individuals cannot show a vestibular type of nystagmus. The lesion was sufficiently deep to destroy the cortico-bulbar fibers from each frontal cortex and the cortico-tegmental fibers from each preoccipital and occipital area as they

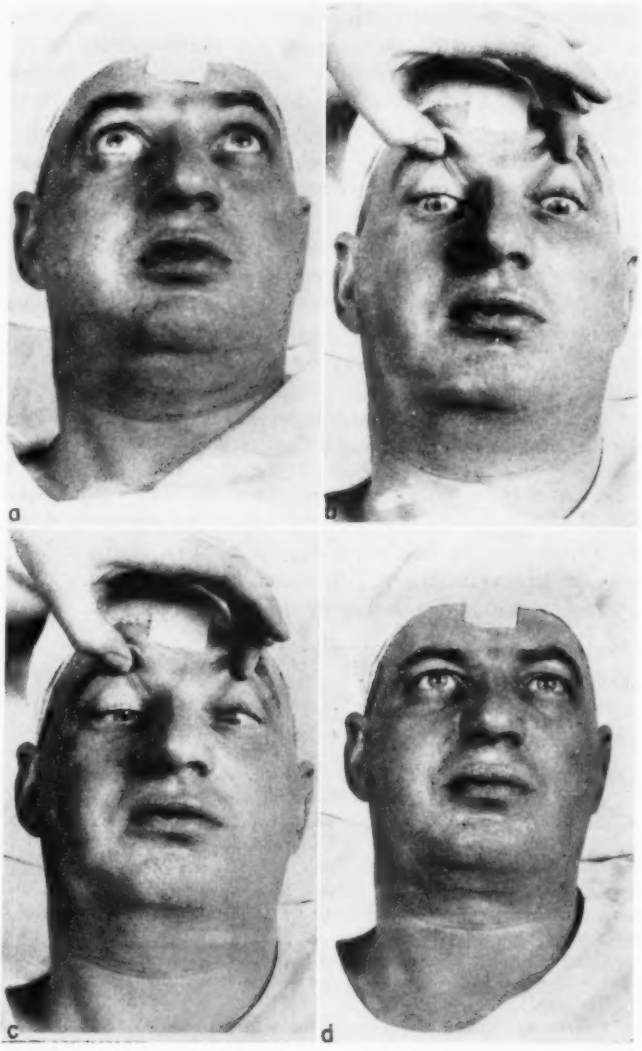

Fig. 4.—Photographs of the patient discussed in the accompanying case history. A, deviation of eyes upward on command; B, deviation of eyes downward on command; C, convergence; D, gaze straight ahead when asked to look toward either side. Note the peculiar staring appearance of the eyes.

crossed the midline beneath the medial longitudinal fasciculi at abducens levels, since he had lost completely the following movements and the voluntary eye movements toward either side. Destruction or lack of function of the labyrinths of both ears would produce a loss of fine movements and vestibular reflexes of the eyes in all planes (probably ordinarily associated with deafness) but without the loss of voluntary and following movements of the eyes in any plane. From the foregoing account it is obvious that the abducens nuclei (with their associated parabducens cells) and the medial longitudinal fasciculi constitute the final common centers and the final common paths, respectively, for eye movements in the horizontal plane, whether such movements are voluntary deviations or following movements of the eyes toward either side or are elicited as parts of a vestibular response. It is obvious also that voluntary and following movements of the eyes in vertical planes and convergence do not depend on connections through the parabducens nuclei.

Evidently then nystagmus is initiated not only by lesions in the peripheral vestibular system but by lesions in the central nervous system at different levels. Moreover, the position of the lesions within the central nervous system is indicated by the other signs and symptoms which accompany the nystagmus.

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DEPT. OF ANATOMY.

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XCVI

THE OTOTOXICITY OF DIHYDROSTREPTOMYCIN AND NEOMYCIN IN THE CAT

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A year ago the authors described electrophysiological studies of auditory and vestibular function in cats with varying degrees of chronic intoxication with streptomycin and demonstrated corresponding degenerative changes in the neuroepithelium of the ampullar cristae, the maculae and the organ of Corti.[12] The histological findings fully confirmed the earlier conclusion, based on the observation that streptomycin caused selective depression of the cochlear microphonic potentials, that the antibiotic must affect primarily the end organs of the eighth cranial nerve rather than the nerve itself or the central pathways.[8] The observations were also in substantial agreement with the descriptions of lesions produced by streptomycin treatment in the mouse,[6] in the vestibular end organs of the cat,[2, 3] and in the guinea pig.[10]

In the present paper, similar experiments in cats treated with dihydrostreptomycin and neomycin are to be reported. Electrophysiological studies of the effects of dihydrostreptomycin on vestibular function were first carried out by one of us in 1948 and published as a part of the experimental evaluation of the drug by Edison *et al.*[7] Both these animal experiments and the clinical studies by Hobson *et al*,[14] and Hinshaw *et al*,[13] showed that dihydrostreptomycin was significantly less toxic than streptomycin for the vestibular system. From subsequent clinical reports, however, it has become clear that dihydrostreptomycin has a greater tendency than streptomycin

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to cause impairment of hearing in human patients.[4, 18, 21] While the dihydrostreptomycin used in some of the early clinical investigations appears to have contained impurities which made it more ototoxic than present-day, highly purified material[9] the results of a recent large-scale clinical comparison of samples of streptomycin and dihydrostreptomycin of satisfactory purity reported by Lyght and Hawkins[17] show once more that in man prolonged treatment with dihydrostreptomycin more frequently affects auditory acuity, while streptomycin more frequently causes a disturbance of vestibular function.

Previous work in cats has shown that after dihydrostreptomycin treatment the cochlear microphonic response is generally unchanged.[9] The closely related hydroxystreptomycin proved so toxic for both the auditory and the vestibular systems of the cat that it was withheld from clinical trial.[10] Neomycin, which in clinical investigations was found to cause rapid and profound loss of hearing as well as renal damage,[5, 22] has been shown to be more toxic for the cochlea than even hydroxystreptomycin.[11]

ANIMALS AND DRUGS

From among some 70 cats treated with various samples of dihydrostreptomycin and 34 treated with neomycin preparations, in all of which vestibular and auditory function had been followed, four were chosen from each series for histological study. These were the animals which had received the most prolonged and intensive treatment with the antibiotics and might therefore be expected to show the most clearly defined lesions. Carefully selected before treatment, they had been given injections of the antibiotics once daily by the subcutaneus route, in varying doses.

The dihydrostreptomycin used was in the form of the crystalline sulfate (Merck), having a potency of approximately 800μg base per mg of substance. Two cats received 800 mg base per kg of body weight daily for 15 days (total dose 12.0 gm/kg), and two others received 200 mg base per kg of body weight daily for 120 days (total dose 24.0 gm/kg).

The neomycin was a preparation intended for clinical investigative use.* Although it was by no means pure, it appeared to be

*This material was submitted to us by Dr. Henry Welch of the U. S. Food and Drug Administration for ototoxicity tests.

mostly neomycin B, and it had a potency of 208 units/mg, according to the statement on the label. Since there is no established simple relationship between the potency and purity of neomycin preparations, doses were measured in terms of weight of substance rather than of base. The daily and total doses of neomycin were relatively smaller than in the case of dihydrostreptomycin, ranging from 40 to 100 mg/kg daily, and from 0.8 to 3.0 gm/kg in total amount.

EXPERIMENTAL METHODS

In all cases the animals' posture and gait was observed daily, and frequent quantitative tests of vestibular function were made by recording the per and postrotatory nystagmus in response to a standard stimulus on a motor-driven turntable. When vestibular disturbance occurred, it was rated on a 4-point scale according to the degree of ataxia, head oscillation and loss of nystagmus.

At the end of the experiment each animal was anesthetized with pentobarbital sodium, the auditory bullae were opened, and cochlear microphonic and nerve action potential responses to tones and clicks carefully measured at the round window. The minor modifications of the Wever and Bray technique used in this work have already been described.[8, 9]

With the cat still anesthetized, the carotid arteries were cannulated and the jugular veins incised, so that the temporal bones could be fixed *in situ* by perfusion of the head. As in our previous work we followed the method of Koenig *et al*,[15] perfusing at a hydrostatic pressure of approximately 120 mm Hg to reproduce the mean arterial pressure, and using 5.6% gum acacia in 0.9% NaCl solution as a perfusion fluid having a similar colloid osmotic pressure to that of blood, followed by the same solution plus 10% formalin as a fixative.

After removal, the temporal bones were further fixed in Heidenhain's Susa solution. They were decalcified in 5% trichloracetic acid solution and run through the alcohols and ether in preparation for embedding them in celloidin. Serial sections were cut at about 18 microns thickness, every fifth section being stained. Hematoxylin and eosin, the Masson stain, and Heidenhain's Mallory stain were the three types employed.

TABLE I.
VESTIBULAR EFFECTS.

Cat No.	Dose mg/kg	Duration of Rx days	Onset of Ataxia days	Max. Vestibular Disturbance	Histological Findings Crista	Macula
Dihydrostreptomycin:						
1327	800	15	8	+++	marked scattered degen.	normal
1330	800	15	10	++++	marked scattered degen.	normal
1365	200	120	28	++++	scattered degen.	normal
1367	200	120	78	++	scattered degen.	normal
Neomycin:						
1412	100	8	—	—	normal	normal
1408	100	30	—	±	slight scattered degen.	normal
1448	80	15	—	—	normal	normal
1397	40	60	—	—	normal	normal

Note: Cat 1408 showed loss of nystagmus in response to rotation on the 35th day.

RESULTS

DIHYDROSTREPTOMYCIN

a. *Vestibular System:* Disturbance of vestibular function in the dihydrostreptomycin-treated cats ranged from moderate to severe, as shown in Table I. In the pair treated with 200 mg/kg daily, ataxia first appeared after 28 and 78 days, whereas with a similar dose of streptomycin ataxia appears after 9 to 13 days (average 10 days). With the 800 mg/kg dose the latency of the vestibular disturbance was shortened to 8 and 10 days. No comparable figures are available for streptomycin, since the maximum tolerated dose of streptomycin lies between 400 and 600 mg/kg.

The cristae of the horizontal semicircular canals showed scattered degeneration of hair cells, more marked in the cats receiving the short-term, intensive treatment than in the other pair (Figs. 1-4). The maximum functional deficit had been greater in cat 1365 than in 1367, but 1365 showed less extensive degeneration of the hair cells. It should be noted, however, that the degree of vestibular disturbance shown in the table was that present at the height of the intoxication. By the time the animals were sacrificed about two months later, some measure of recovery of function had occurred in each case. In none of the four animals was the degeneration as extensive as that seen in the streptomycin-treated cats illustrated in our previous paper, nor were degenerative changes in the maculae striking.

b. *Cochlea:* Table II shows the results of the microphonic studies in terms of the maximum voltage recorded at the round window in response to tones of five different frequencies. There is little difference between the response of the dihydrostreptomycin-treated cats and the normal control animals. Cat 1365 showed a slight depression of the response, while 1367 showed an enhancement, which is statistically significant at the higher frequencies (2000-8000 cps). Cats 1327 and 1330 were less affected in this respect, 1327 showing a slight depression in the left ear.

Although these microphonic changes appear relatively insignificant, in contrast to those previously observed in our streptomycin-treated cats, it must be emphasized that the action potential component of the response to clicks was depressed even when the microphonic response was enhanced. This change is also in contrast to

that after streptomycin, which selectively depressed the microphonic components (Fig. 5).

In cats 1327 and 1330, the organ of Corti appeared to be normal throughout (Fig. 6). Cats 1365 and 1367 showed degeneration of the external hair cells in the second and third turns and, in the case of 1365, in the upper one-third of the first turns as well. The internal hair cells appeared normal (Figs. 7 and 8).

NEOMYCIN

a. *Vestibular System:* In the neomycin-treated cats no ataxia occurred at any time. Nevertheless cat 1408, which received the largest total dose, 100 mg/kg for 30 days, showed a loss of nystagmus in response to rotation on the thirty-fifth day. The crista of this animal revealed a slight, scattered loss of hair cells when examined under the high power (Fig. 9), while the others appeared entirely normal (Figs. 10-12).

b. *Cochlea:* Neomycin caused a profound loss of cochlear function in all four cats. In fact cat 1412, which had the shortest period of treatment, was the only one from which any cochlear response could be recorded at all. The organ of Corti showed degeneration of the external hair cells in the first turn and in the lower half of the second turn, with scattered degeneration in the upper half of the second turn and in the third turn. The internal hair cells appeared normal (Fig. 13). In the other animals there was complete degeneration throughout the cochlea of both external and internal hair cells (Figs. 14, 15). There was no evidence of shrinkage or reabsorption of the organ of Corti, such as occurred in one of our streptomycin-treated cats and in several of the guinea pigs of Rüedi and his colleagues. Had the neomycin-treated animals been kept for longer periods after treatment, the organ of Corti might have been reabsorbed, as we have shown it to be after severe acoustic trauma.[16]

The auditory nerve appeared to be unaffected; fibers could be seen crossing the tunnel of Corti, and the cells of the spiral ganglion were not remarkable. No changes were observed in the stria vascularis.

COMMENT

The mode of action of the antibiotics upon the end organs of the eighth nerve remains unknown, as do also the reasons for their

TABLE II.
COCHLEAR EFFECTS

Cat No.	Dose mg/kg	Duration of Rx days	Tested days post Rx	Ear	Maximum Microphonic Response db below 1 mv 500	1000	2000	4000	8000 cps	Histological Findings Ext. hair cells	Int. hair cells
Dihydrostreptomycin											
1327	800	15	70	R	7	4	5	7	12	normal	normal
				L	10	7	9	10	14		
1330	800	15	69	R	5	0.5	2	4	8.5	normal	normal
				L	7	2	2	4	9		
1365	200	120	55	R	14.5	10	11.5	13	19	degen. upper third of 1st turn, also 2nd and 3rd turns	normal
				L	11.5	7.5	9.5	12.5	18.5		
1367	200	120	56	R	4	1.5	1	3	8	degen. 2nd and 3rd turns	normal
				L	2	+0.5	+0.5	0.5	5.5		
Neomycin											
1412	100	8	1	R	27	24	27	30	40	degen. 1st turn and lower half 2nd turn; scattered degen. upper half 2nd turn and 3rd turn	normal
				L	30	25	27.5	31	31		
1408	100	30	8	R	— no response —					complete degeneration	
				L	" "						

1448	80	15	7	R L	— no response — " "					complete degeneration
1397	40	60	12	R L	— no response — " "					complete degeneration
Normal Controls										
1422				R	6	3.5	3	6	12	
				L	7	2	3	4.5	10	
Means for 28 normal ears					5.1	2.6	3.0	5.1	9.6	
Standard Error of Mean					±0.6	±0.4	±0.3	±0.4	±0.5	

remarkable differences in specificity. The latter are especially striking in the contrast between the cochlear effects of streptomycin, which we have shown to affect primarily the internal hair cells and the microphonic potentials, and dihydrostreptomycin, which now appears to act upon the external hair cells and the action potentials of the auditory nerve. Why neomycin should have so little effect upon the vestibular end organs and cause such profound changes in the cochlea is also unexplained. Obviously the argument that one structure or system is more or less primitive than the other and therefore more or less rugged can have very little to do with the case, since the relative susceptibilities to neomycin are exactly the reverse of those to streptomycin.

It is our impression that loss of function usually precedes the occurrence of visible damage to the neuroepithelium. In the cochlea the strongly basic antibiotics may gradually decrease the polarization of the organ of Corti, reducing the strong DC potential which Békésy[1] has found inside the cochlear partition between the organ of Corti and the endolymph. Unfortunately, no measurements similar to his have been made in either normal or antibiotic-treated cats. The guinea pig, which Békésy has used, would be less suitable for this purpose because it is peculiarly refractory to the ototoxic effects of antibiotics, even neomycin.

The specificity of these substances for the labyrinthine structures and not for other nerve endings is presumably bound up with a special route of access to the inner ear. They may reach it by being secreted with the endolymph as Rüedi[20] has suggested, or by way of the cerebrospinal fluid and the perilymph. The latter route seems the more likely, since we have found that the ototoxic effect of moderate doses of streptomycin and dihydrostreptomycin is greatly enhanced and the latency is shortened when minute amounts are also given by intracisternal injection. This fact would seem to explain the severe deafness which has been produced in some patients with tuberculous meningitis treated with dihydrostreptomycin by the intrathecal route.

Although the electrophysiological tests do not measure actual hearing in cats, and no conditioned response studies have been made, it appears that the cochlea of the cat is less sensitive to dihydrostreptomycin than to streptomycin, while it is known that the human cochlea is more sensitive to dihydrostreptomycin. Since in man

it is the threshold of hearing for the highest frequencies which is first affected by dihydrostreptomycin one may infer that the antibiotic acts first upon the external hair cells in the basal turn of the human cochlea, rather than upon those of the second turn as it does in the cat.

The severe ototoxicity of neomycin in both species shows that it is obviously unsuitable for prolonged use in the chemotherapy of tuberculosis. Although more highly purified neomycin B was less ototoxic than the material reported here, it was still too toxic for clinical use. Only neomycin A showed relatively little ototoxic effect, but it is eliminated from consideration by the fact that its tuberculostatic activity is negligible.[11]

SUMMARY

1. Intensive treatment with dihydrostreptomycin caused a disturbance of vestibular function in cats, associated with scattered degeneration of the hair cells of the ampullar cristae. The effect was later in onset and less severe than with streptomycin.

2. The microphonic potentials of the cochlea were little affected, but the action potential component of the round window response was depressed. There was degeneration of the external hair cells, especially in the second and third turns; the internal hair cells were unchanged. The cochlea of the cat is less sensitive to dihydrostreptomycin than to streptomycin, although in man the reverse is true.

3. Neomycin in smaller doses had little or no effect on vestibular function, but it caused severe or complete degeneration of the hair cells of the organ of Corti, and corresponding loss of microphonic and nerve action potentials.

ACKNOWLEDGEMENT—The authors wish to recognize with gratitude the technical skill of Mr. Walter J. O'Shanny, of the Merck Institute for Therapeutic Research, in treating the cats and in carrying out the vestibular tests, as well as the expert histological technique of Miss Dorothy Linden, of the Massachusetts Eye and Ear Infirmary.

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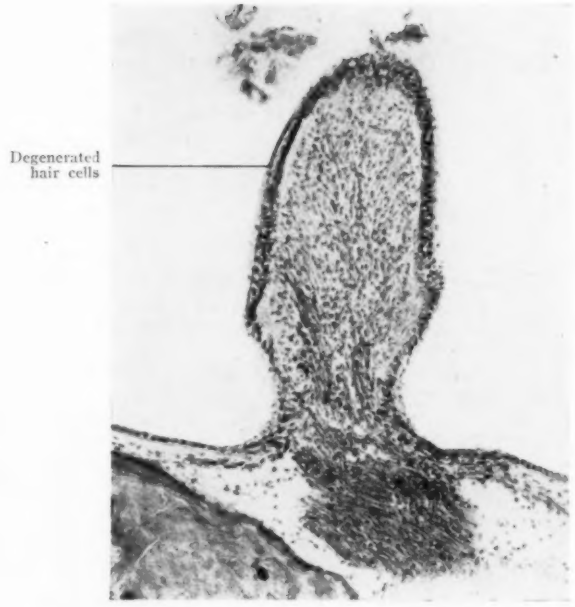

Fig. 1.—Animal No. 1327. Crista (x 190). Dihydrostreptomycin 800 mg/kg/day s.c. 15 doses. Scattered degeneration of hair cells.

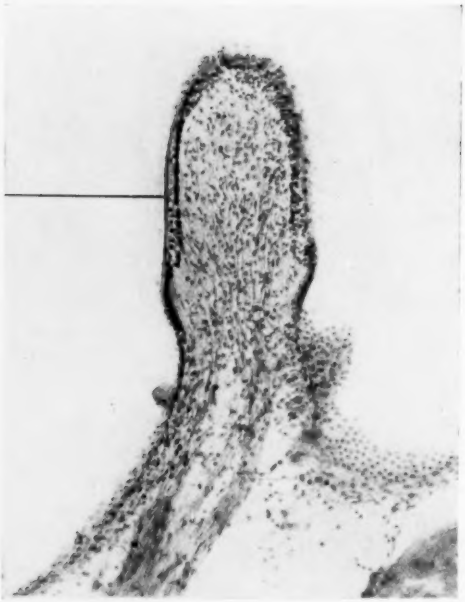

Fig. 2.—Animal No. 1330. Crista (x 190). Dihydrostreptomycin 800 mg/kg/day a.c. 15 doses. Scattered degeneration of hair cells.

Fig. 3.—Animal No. 1365. Crista (x 200). Dihydrostreptomycin 200 mg/kg/day s.c. 120 doses. Scattered degeneration of hair cells. Compare with Fig. 4 and Fig. 1.

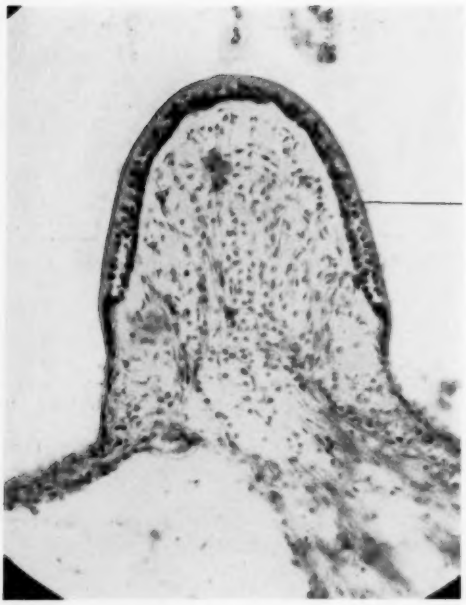

Fig. 4.—Animal No. 1367. Crista (x 215). Dihydrostreptomycin 200 mg/kg/day s.c. 120 doses. Slight scattered degeneration of hair cells.

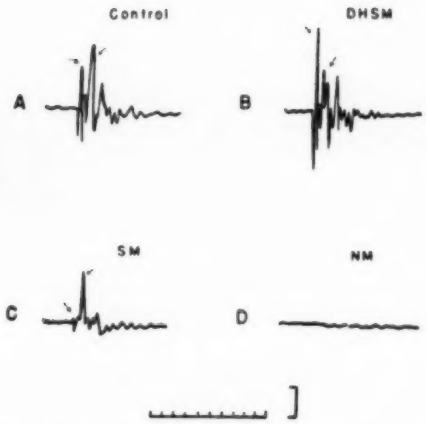

Fig. 5.—Response to acoustic clicks, as recorded from the round window, in four different cats. The first portion of each response represents the cochlear microphonic potential (first arrow), which is followed by the action potentials of the auditory nerve (second arrow). The intensity of the click stimulus was the same in all cases, ca. 50 db above human threshold.

A. Cat 1422, Normal control, showing both microphonic and action potentials well developed.

B. Cat 1367, Dihydrostreptomycin, showing enhanced microphonic response and depressed action potentials.

C. Cat 1395, Streptomycin, showing typical selective depression of microphonic potential.

D. Cat 1412, Neomycin, showing loss of both components. At higher intensities a small action potential component appeared. Time: milliseconds. Calibration: 100 microvolts r.m.s.

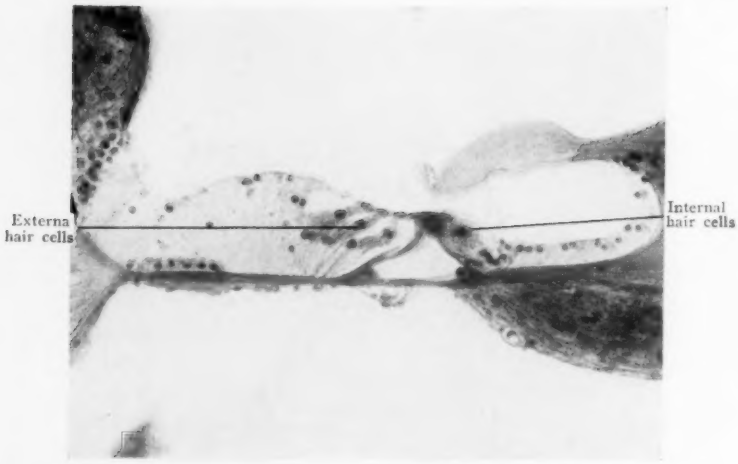

Fig. 6.—Animal No. 1327. Organ of Corti (x 300). Dihydrostreptomycin 800 mg/kg/day s.c. 15 doses. Normal.

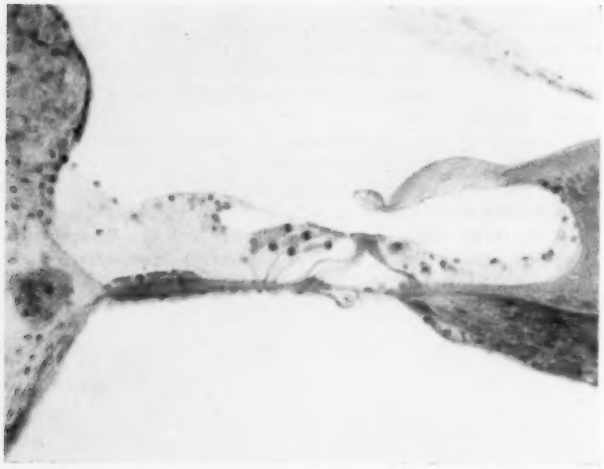

Fig. 7.—Animal No. 1367. Organ of Corti 1st turn cochlea (x 300). Dihydrostreptomycin 200 mg/kg/day s.c. 120 doses. Normal organ of Corti.

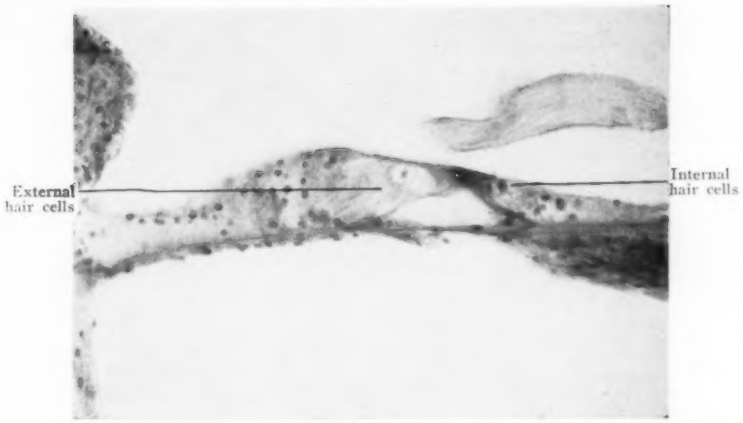

Fig. 8.—Animal No. 1367. Organ of Corti 2nd turn cochlea (x 300). Dihydrostreptomycin 200 mg/kg/day s.c. 120 doses. Degeneration of external hair cells. Internal hair cells present.

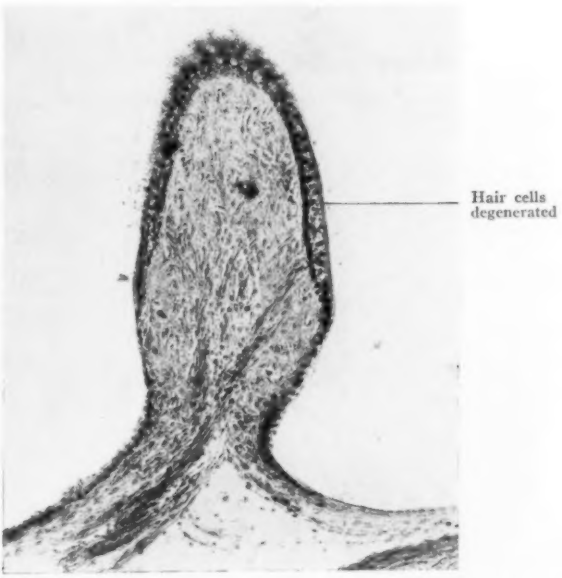

Fig. 9.—Animal No. 1408. Crista (x 215). Neomycin 100 mg/kg/day s.c. 30 doses. Scattered degeneration of hair cells. Compare with crista of animals treated with dihydrostreptomycin.

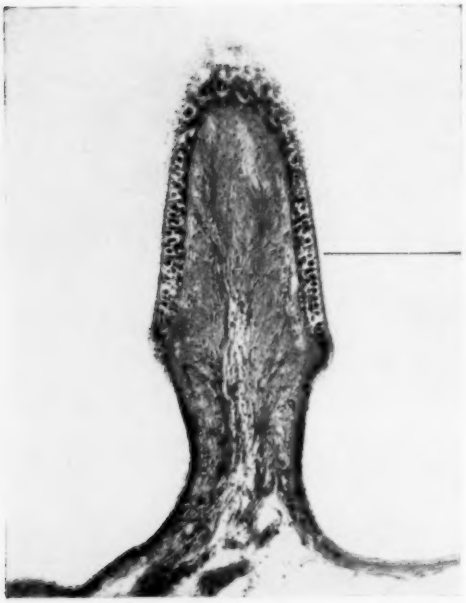

Fig. 10.—Animal No. 1397. Crista (x 160). Neomycin 60 mg/kg/day s.c. 40 doses. Normal crista.

Fig. 11.—Animal No. 1412. Crista (x 65). Neomycin 100 mg/kg/day s.c. 8 doses. Normal crista.

Fig. 12.—Animal No. 1448. Crista (x 65). Neomycin 80 mg/kg/day s.c. 15 doses. Normal crista.

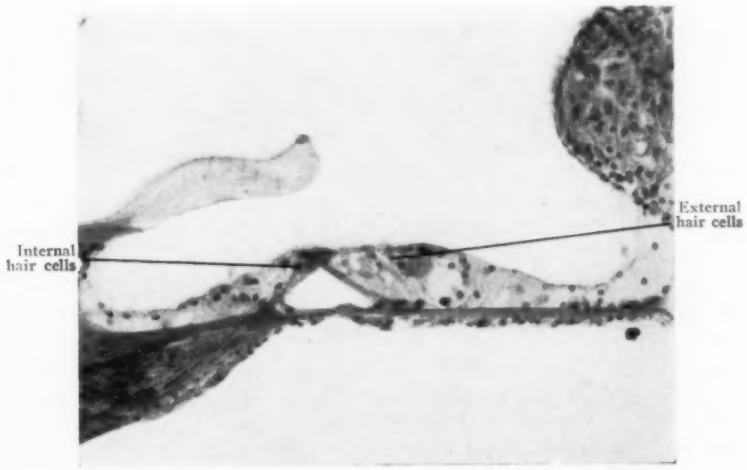

Fig. 13.—Animal No. 1412. Organ of Corti (x 300) 1st turn cochlea. Neomycin 100 mg/kg/day s.c. 8 doses Degeneration of external hair cells. Internal hair cells normal. Scattered degeneration of external hair cells of the 2nd and 3rd turns.

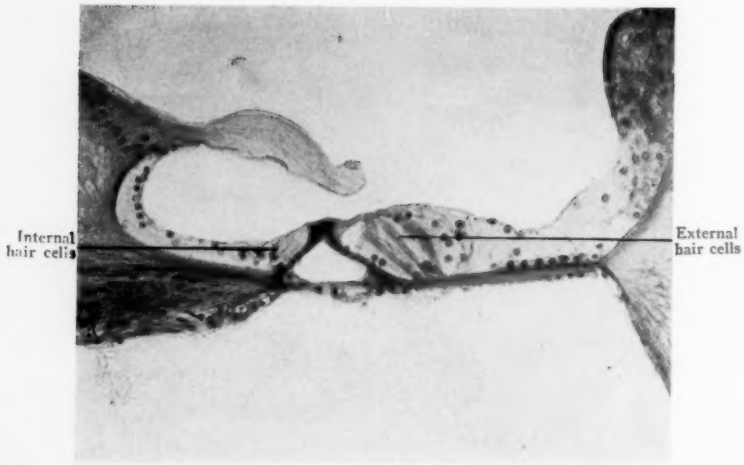

Fig. 14.—Animal No. 1408. Organ of Corti (x 300) 1st turn cochlea. Neomycin 100 mg/kg/day s.c. 30 doses. Degeneration of internal and external hair cells. 2nd and 3rd turns also have complete degeneration of internal and external hair cells.

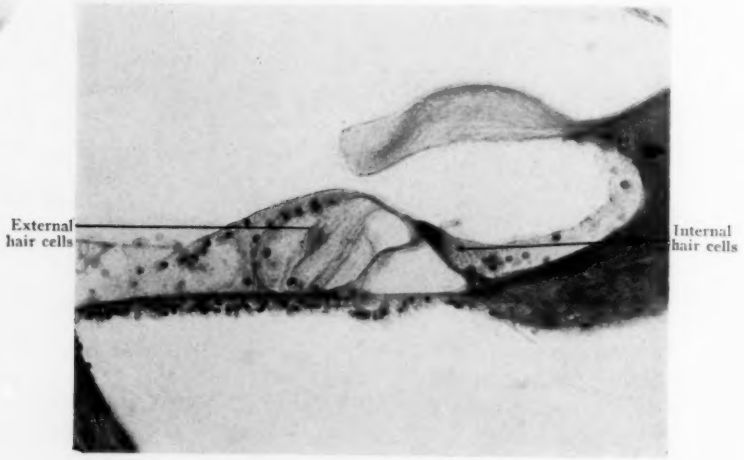

Fig. 15.—Animal No. 1448. Organ of Corti (x 300) 1st turn cochlea. Neomycin 80 mg/kg/day s.c. 15 doses. Complete degeneration of internal and external hair cells. 2nd and 3rd turns also have complete degeneration of internal and external hair cells.

XCVII

A RESEARCH STUDY OF THE EFFECT OF THE AUTONOMIC NERVOUS SYSTEM ON THE INTERNAL EAR

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Since the beginning of this century many have entertained the idea that the proper function of the inner ear may be upset by an imbalance of the autonomic nervous system. A dysfunction of the autonomic nervous system is said to lead to a circulatory disturbance and thereby to produce various disease conditions of the cochlea and the vestibular labyrinth. More recent conceptions of this general explanation for inner ear disorders have been referred to as vasomotor labyrinthitis, vasomotor labyrinthine ischemia, or allergy of the inner ear. This hypothesis, that neurovascular disturbances in the inner ear can be brought about by autonomic imbalance, is being used today as a basis of treatment both surgical and medical, for Ménière's disease, tinnitus, sudden deafness, and nerve deafness.

More particularly, an autonomic imbalance is said to produce a state of spasm in the arterioles of the inner ear. This spasm, it is believed, leads to capillary and venous congestion resulting in an alteration in the permeability of the capillary walls. When this reaction takes place in the vessels of the stria, an excess of endolymph is thought to be secreted which can cause hydrops of the labyrinth. When the reaction takes place in the vessels supplying the cristae and maculae, the result is thought to be a local anoxia with eventual organic change.

From the Lempert Institute of Otology and Lempert Research Foundation, Inc.

A revival of interest in this line of reasoning in recent years has led to a tendency to accept these hypotheses as a new approach to the etiology of inner ear diseases. Actually, these concepts go back many years. In 1904, Ferreri[1] pointed out certain affections of the internal ear in connection with sympathetic lesions and used the term "glaucoma" to designate hypertension of the endolymphatic fluid. In 1906, George Shambaugh, Sr.,[2] postulated that vasospasm was the cause of recurring attacks of Ménière's disease. In that same year, Escat[3] devoted a great deal of space to vascular spasm in the pathogenesis of Ménière's disease. In 1919, Lermoyez[4] elaborated upon the clinical variations which might result from the spasm in the vestibular or cochlear branches of the internal auditory artery. Twenty-five years ago, in a paper entitled "Vasomotor Affections of the Internal Ear," Georges Portmann,[5] in reviewing the ideas of that day, attributed to Quincke, Wittmaack, S. H. Mygind, and Hwidt the belief that the symptoms of Ménière's disease were due to pressure in the endolymphatic system which was related to vasomotor trobules. He attributed to Kobrak the belief that the symptoms were directly related to the autonomic nervous system. Portmann himself suggested a connection between increased endolymphatic pressure and capillary stasis, which he thought in turn to be due to vasomotor phenomena.

Paralleling these theoretical reports concerning the etiology of inner ear disorders have been the appearance of clinical reports along the same line. These have been concerned with efforts to treat internal ear conditions by attempting to influence the autonomic nervous system with drugs or by surgery. Although these reports have been coming out over a period of almost fifty years,* they have failed to resolve the question of the influence of the autonomic nervous system on the internal ear. This is perhaps due to the difficulties, familiar to all clinicians, in evaluating the results of treatment of diseases of the internal ear which are notoriously famous for periods of exacerbation and remission. During this long period there has also been very little convincing experimental evidence to support or deny this theory. Lindsay,[6] in giving the Wherry Memorial Lecture of 1952 on "Some Experimental Observations Bearing on Ménières' Disease," had to state: "The effect of the autonomic nervous

*A recent excellent review in this field is to be found in the article by R. S. Lewis: Sympathectomy of the Internal Ear, J. Laryng. & Otol. Vol. LXV, No. 12, 825, 1951.

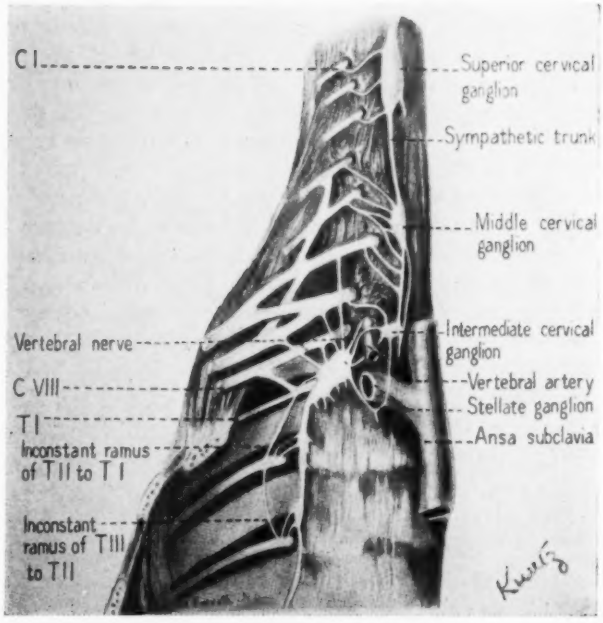

Fig. 1.—The cervical and upper thoracic portions of the sympathetic trunk. (From The Autonomic Nervous System, by A. Kuntz, Lea & Febiger, by kind permission of author and publishers.)

supply on the vessels of the stria vascularis and the sensory receptors has not yet been adequately studied."

There are two principle suppositions in this theory: 1) that an imbalance of the autonomic system can cause the arterioles to shut down sufficiently to result in ischemia, and 2) that the resulting ischemia leads to certain affections of the inner ear which may be generally referred to as changes in fluid balance or damage to the sensory receptors.

As regards the latter supposition, there can be no question that a disruption of blood supply to an organ causes grave disorders in its functional and physical well-being. If the blood supply to the vessels of the stria vascularis or sensory receptors is interfered with,

it is logical to expect physical changes in the inner ear, and, consequently, to expect symptoms referable to those changes. The question is whether such an interference to the blood supply can result from an autonomic imbalance. In other words, can the autonomic nervous system cause the arterioles to shut down sufficiently to result in ischemia? We are told by the advocates of this theory that an ischemia can arise in this manner; that the two subdivisions of the autonomic nervous system supplying the inner ear, the sympathetic and the parasympathetic, are physiologically antagonistic and normally in a state of balance; that when this balance is upset in one direction or the other, causing a state of sympathetic dominance or parasympathetic dominance, then dysfunction results. There are proponents of this theory today who explain diseases of the inner ear by a dominance of the parasympathetic division, whereas others explain them by a sympathetic dominance.

Because of the clinical implications involved in the use of this theory as a basis of treatment, we have been prompted at the Lempert Institute of Otology to carry out on monkeys experiments which have been designed to test this theory. The investigations were conducted in two series—one series in which parasympathetic dominance was produced, and a second series in which sympathetic dominance was produced. The method consisted of a complete surgical denervation of the sympathetic supply to the inner ear in series one, and of the parasympathetic supply in series two. It is clear that the elimination of one division of the autonomic system must produce a maximum imbalance, and, if the proponents of the theory in question are correct, obvious abnormalities of the inner ear should occur.

DENERVATION OF THE SYMPATHETIC SUPPLY TO THE INNER EAR

Although it is generally accepted that sympathetic fibres reach the inner ear along the internal auditory artery, there is no direct evidence as to which spinal segments supply these fibres nor what pathways they follow to reach the internal auditory artery. Very little work has been done in denervation of the cephalic area to clear up these questions. There is, therefore, a variation in opinion as to the technique best suited to this purpose.

There are several operations which have been used in attempts to influence the internal ear through the sympathetic system.

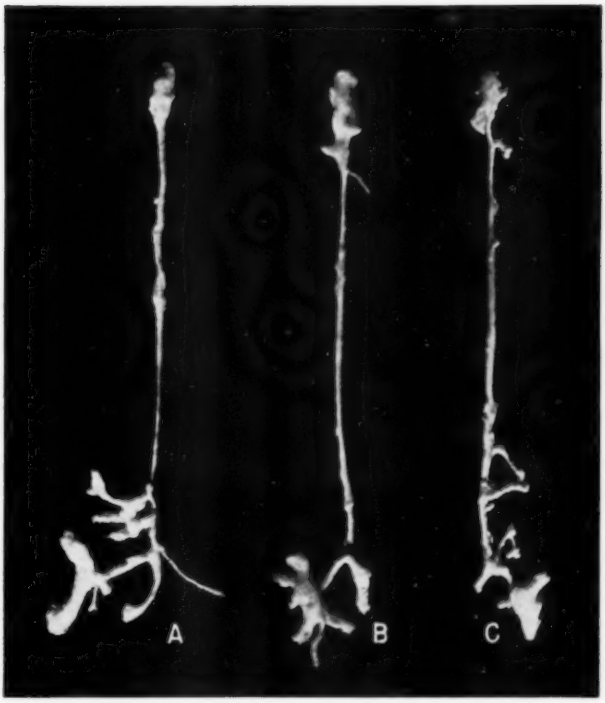

Fig. 2.—Examples of actual specimens at operation, showing wide removal of the cervical and upper thoracic portions of the sympathetic trunk. A. Specimen from unilateral (right) sympathectomy, Monkey No. 141. B. and C. Specimens from bilateral sympathectomy, Monkey No. 145.

1) Periarterial sympathectomy or decortication of the common carotid artery was frequently used for this purpose. This operation was at one time employed in a wide variety of clinical conditions involving the arteries of the extremities. With increasing knowledge of the anatomy and physiology of the autonomic nervous system, however, it has fallen into disuse in recent years. Results reported in the literature have also proven it to be an inadequate procedure.

2) Mogan and Baumgartner (1945)[7] described the removal of the superior cervical sympathetic ganglion to stop vasoconstric-

tive impulses to vessels of the ear. This procedure would not insure complete denervation of the cephalic area because it leaves the sympathetic rami along the vertebral artery intact (Fig. 1) so that the cerebral vessels are only partly cut off from their vasoconstrictor nerves. It is interesting in this connection that when the superior cervical ganglion was removed by Forbes and Cobb[8] they saw no dilatation of the pial vessels they were watching through a window in the skull.

3) Passe (1952)[9] reported a series of cases of Ménière's disease, nerve deafness, and tinnitus that were said to be successfully treated by sympathectomy. The procedure he used was to divide the preganglionic fibres from the second and third thoracic anterior roots and the trunk below the third ganglion. This is an operation devised by Telford (1935)[10] and Smithwick (1936)[11] as a preganglionic section of the sympathetic supply to the upper limb for Raynaud's disease. It avoids a Horner's syndrome. It is also thought to avoid sensitization of the sympathetically denervated structures to adrenalin in the circulating blood. It is possible to use this procedure to successfully denervate the upper extremity because of the assumption, probably correct, that preganglionic fibres of the first thoracic nerve play no important role in the sympathetic innervation of the upper extremity. However, the same fibres do in most cases carry impulses to the head and neck. Therefore, when this same operation is used to denervate the cephalic area it is likely to be incomplete.

4) In his earlier papers (1948) Passe[12] described the procedure of interrupting the posterior ganglionic chain by means of stellate ganglionectomy. The operation, which Passe abandoned after his earlier operations in favor of the Smithwick procedure, is more likely to denervate the cephalic area than is the Smithwick procedure which leaves intact the sympathetic fibres of the first thoracic nerve. It does not, however, assure complete denervation of the head and neck. Skoog (1947)[13] has demonstrated the presence of sympathetic ganglia in the communicating rami close to the spinal nerves of the cervical and upper two thoracic segments. It is possible, as Lewis[14] has pointed out, that these so-called intermediate ganglia of the communicating rami may receive their preganglionic fibres from the spinal nerves while their postganglionic fibres enter either the sympathetic trunk or run directly to one of the periarterial plexuses.

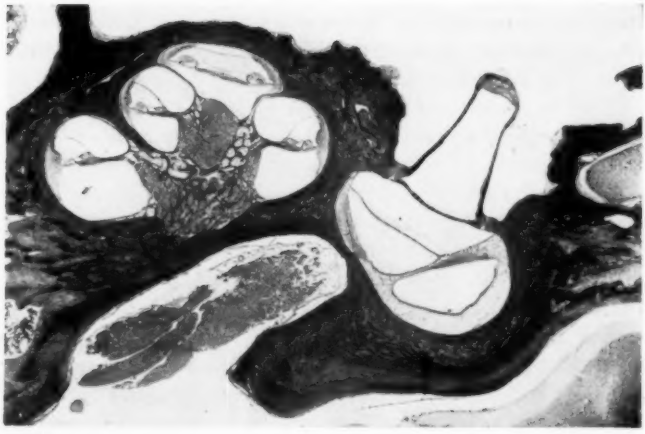

Fig. 3.—Monkey No. 141. Unilateral (right) sympathectomy. Sacrificed ten days post-operatively. Above is the right ear showing normal sensory receptors and no evidence of distortion from fluid changes.

Therefore, after stellate ganglionectomy it is still possible that fibers may enter the sympathetic chain from the cervical cord.

COMPLETE DENERVATION

To be sure of complete sympathetic denervation of the cephalic area, it is clear that the sympathetic chain and ganglia must be removed widely from the jugular foramen above, down to the second thoracic ganglion below. Experimentally, this can be done without regard for the extensiveness of the procedure or the appearance of Horner's syndrome.

TECHNIQUE

Anesthesia was induced by intravenous injection of pentobarbital sodium. During the operation the animal received a venoclysis of five per cent dextrose in distilled water.

Denervation of the sympathetic nerve supply to the internal ear was approached by making an incision along the anterior border of the right sternocleidomastoid muscle from the mastoid tip to the sternoclavicular joint. Superficial and deep neck fascia was divided.

The carotid sheath was opened and its structures identified. The cervical sympathetic chain was located in the deep neck fascia and dissected free to the jugular foramen where it was divided above the superior cervical ganglion at the jugular foramen. The chain was then dissected free inferiorly to the intermediate cervical ganglion (Fig. 1). The vertebral artery was located, tied and divided inferiorly at its origin from the subclavian artery and also tied and divided superiorly at the beginning of its course through the foramina at the transverse processes of the cervical vertebrae. The loop of the cervical chain connecting the intermediate ganglion to the stellate ganglion anterior to the subclavian artery was divided. The stellate ganglion was then removed, still attached to the entire cervical chain (Fig. 2), by dividing the sympathetic trunk just above the second thoracic ganglion and severing the multiple connections of the stellate ganglion superiorly. The fascia and skin edges were sutured. At the completion of the operation, 400,000 units of penicillin were given intramuscularly.

A great deal of sympathetic surgery has been done for vascular disease of the extremities, and recently for hypertension. Problems which have appeared in this work may apply also to sympathetic denervation of the cephalic area. These problems are:

1) *Necessity for complete denervation.* Kuntz[15] has stated: "In order to produce lasting physiological results, sympathetic denervation of an extremity or viscus must be complete and carried out in such a way that regeneration cannot take place."

We have already shown that to be complete the entire sympathetic chain and ganglia from the second thoracic ganglion up to the jugular foramen must be removed. There is still the further question of the possibility of the cerebral vessels being supplied from both cervical chains which may contribute to a common plexus about the basilar artery or the circle of Willis. In this case the internal auditory artery on one side might receive vasoconstrictor fibres from the other side of the body. It is interesting in this connection that Forbes and Cobb[8] in extensive investigations found that without exception no vasoconstriction occurred on stimulation except on the same side of the head as the nerve stimulated.

Nevertheless, in order to test this question, we have removed in one monkey of the series the cervical sympathetic and stellate ganglia from both sides of the body. When the cervical sympathetic

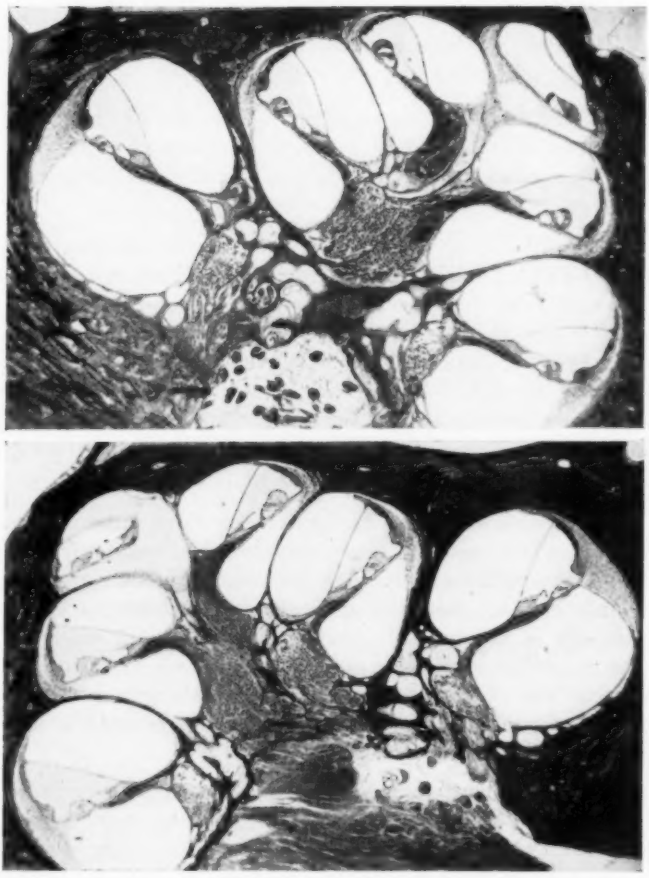

Fig. 4.—Monkey No. 145. Bilateral sympathectomy was done on this animal. Sixty days postoperatively the animal was sacrificed. Above is the right cochlea, below, the left. Both ears appear to be within normal limits and show no distortion resulting from fluid changes.

chain was removed on the left side, the same procedure was followed as just described, with the added precaution of identifying and pushing aside the thoracic duct. The left vertebral artery was kept intact to avoid any possibility of embarrassment to the basilar blood flow. However, the branch coursing to it from the stellate ganglion was carefully identified and divided.

2) *Avoidance of regeneration.* Considerable powers of regeneration have been claimed for autonomic nerve fibers. However, in this experiment the wide removal practically precludes any possibility of functional recovery.

3) *Possibility of sensitization.* After sympathectomy isolated structures which have lost their nervous connections are said to show an increased irritability to circulating adrenalin and sympathin. This question is now believed to be much less important than formerly. (White, 1948[16]). In relation to cerebral vessels, White and Forbes[17] have shown that when the superior cervical and stellate ganglia are removed, and suitable time is allowed for degeneration of the nerve endings, adrenalin applied locally to the pial vessels causes no greater constriction than it does in the normal animal.

The question of sensitization still seems to be important enough clinically, in less complete operations described previously, to be a factor in the preference of some for a preganglionic over a postganglionic section. Since the wide removal we have carried out experimentally is necessarily a postganglionic section, we must rule out the possibility of sensitization. To do so, we have sacrificed for comparison one of the unilaterally sympathectomized monkeys, at ten days, at which time the sensitization phenomenon is supposed to be at its height (Simons and Sheehan[18]).

These are some of the problems of sympathetic surgery in general which have been considered in causes of success or failure. In our approach to animal surgery, however, we have ample assurances that denervation experiments are effective, at least in areas other than the head and neck. This has been shown in many ways. Herrick, Essex, and Baldes (1932)[19] showed that the blood flow in the sympathetically denervated extremity of dogs increased an average of 100 per cent tested 19 to 34 months after operation. Testing was by means of the Rein thermostromuhr. Britton (1930)[20] measured the volumes of blood per minute flowing through the hind limbs of cats following a unilateral lumbar sympathectomy. He demon-

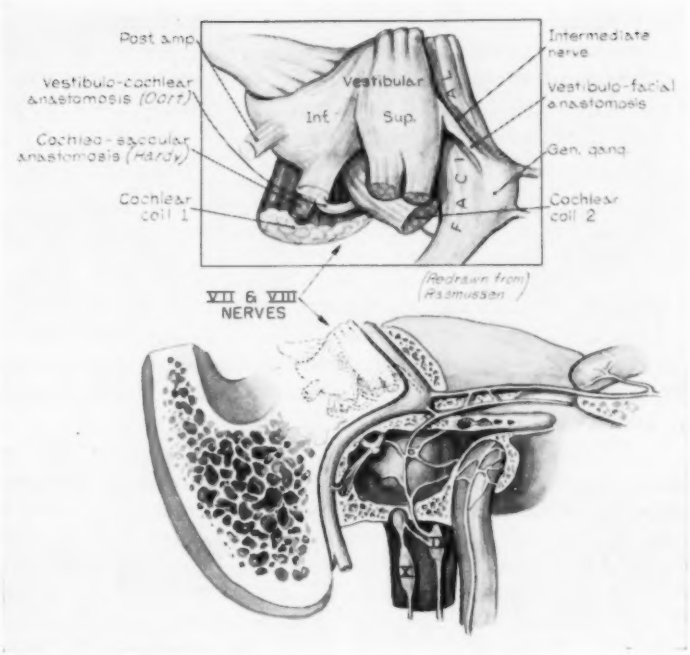

Fig. 5.—Illustrating the neuroanatomical relationships in the internal auditory meatus and the middle ear. (The upper part of this drawing, from a dissection in the cat, is by kind permission of Grant Litster Rasmussen.)

strated that a marked increase in the volume of blood flowing through the capillary bed of the sympathectomized limb is maintained for many weeks. Measurement of heat elimination as well as an increase in the arterial lumen have been other methods utilized to test the effectiveness of denervation experiments.

HISTOLOGICAL PREPARATION OF THE TEMPORAL BONES

All animals were placed under deep narcosis with nembutal and killed by perfusing with Heidenhain "susa" solution via a glass canula inserted through the left ventricle into the aorta. The gravity method was used. In all specimens, on removing the calvarium the brain was

found to be hard and obviously well fixed. The temporal bones were removed from the skull and placed in Heidenhain's-Susa solution within five to ten minutes. The temporal bones were sectioned and stained with hemotoxylin-phloxin stain. In all but one experiment the left ear was sectioned as a control ear, the right as the experimental ear. In the animal in which a bilateral cervical sympathectomy was done, both ears were considered experimental.

RESULTS

Of the seven monkeys used in this series of operations, three were sacrificed for histological study.

Monkey No. 141 had a unilateral sympathectomy on the right side (Fig. 2A). This animal was sacrificed in ten days. All the sensory receptors (organ of Corti, maculae, and cristae), were found to be in good condition (Fig. 3). There was no evidence of distortion from fluid changes.

Monkey No. 142 was an animal in which unilateral sympathectomy was performed on the right side. This animal was permitted to live 60 days. The right ear (experimental ear) showed no abnormalities of the organ of Corti, maculae, or cristae. Reissner's membrane showed a moderate degree of sagging. The left ear (contral ear) also exhibited slight sagging of Reissner's membrane (in basal turn only). This finding was not repeated in the other experimental ears, and since it was in evidence in both ears of this animal, it was considered not significant.

Monkey No. 145 had a sympathectomy performed on both sides (Fig. 2 B and C). This animal was permitted to live for 60 days. Both ears were considered experimental since a bilateral sympathectomy was done. Findings were the same on both sides—normal sensory receptors and no evidence of distortion from fluid changes (Fig. 4).

DENERVATION OF THE PARASYMPATHETIC SYSTEM TO THE INTERNAL EAR

Although there have been a number of experiments on the sympathetic division of the autonomic nervous system, consisting of either stimulating or removing the sympathetic chain, so far as I (J. R.) know there has never been an attempt to determine the in-

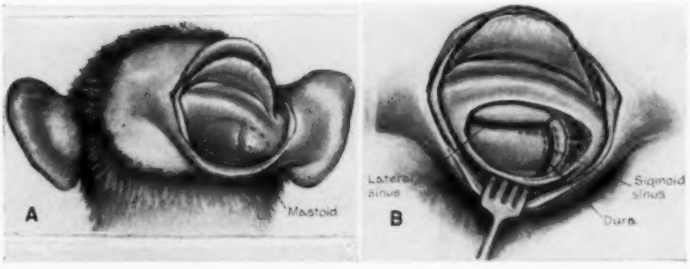

Fig. 6.—Technique of approach to nerves at internal auditory meatus and jugular foramen. A. Area of bone removal. B. Incisions of dura (dotted lines).

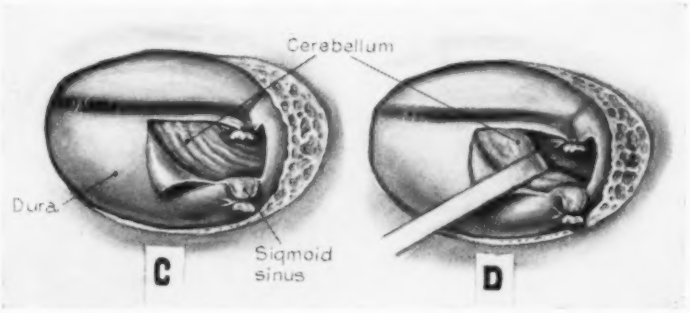

Fig. 6 (Cont.).—C. Ligation and division of sigmoid sinus. D. Retraction of cerebellum.

fluence of parasympathectomy in the internal ear. In working out a procedure for the complete denervation of the parasympathetic fibers to the inner ear, it was recognized that both the source and pathway of these fibres are not definitely known. It was necessary then, to consider all possible sources and pathways, logical and illogical, and isolate the inner ear from their influence. These pathways are:

1) Tract of Rasmussen. In 1946, Rasmussen,[21] investigating the course and relationship of the olivary peduncle, was able to trace this distinct bundle from the superior olivary complex in the brain stem to the cochlea of the opposite side. He found that the peduncular fibres leave the central nervous system between the two divisions of the vestibular nerve and then course in the inferior division of the vestibular nerve as far as the ganglion associated with the main saccular ramus. Beyond the ganglion the fibres pass into Oort's (vestibulo-cochlear) anastomosis (Fig. 5) and reach the cochlea. Further observations have enabled Rasmussen to identify this tract with the spiral fibres of the ganglion of Corti.[22] The morphological features of the peduncular bundle suggest that it is composed of visceral efferent fibres. Rasmussen has suggested that they might be parasympathetic fibres supplying the cochlear blood vessels and the secretory epithelium overlying the stria vascularis. Further evidence to the effect that these fibres are efferent in character is to be found in the investigations of Fernandez,[23] in slides in the collection of Schuknecht,[24] and in the description by Guild[25] of the persistence of the intraganglionic spiral bundle in humans after atrophy of the organ of Corti and the primary neurons.

The cochleo-saccular anastomotic bundle may also represent visceral efferent fibres which innervate the saccule. Although the cells of origin of these fibres are not known, their course peripherally has been described by Rasmussen as being in the vestibular nerve. (Fig. 5).

2) Tympanic nerve. Preganglionic parasympathetic motor fibres from the inferior salivatory nucleus pass peripherally with the glossopharyngeal nerve to the jugular foramen where they leave it as the tympanic branch (Jacobson's nerve). This nerve contributes parasympathetic fibres to the tympanic plexus. It has been suggested by Hilger[26] and others that the connections which exist between the tympanic plexus and the geniculate ganglion, and between the geniculate ganglion and the VIIIth nerve, make it theoretically possible

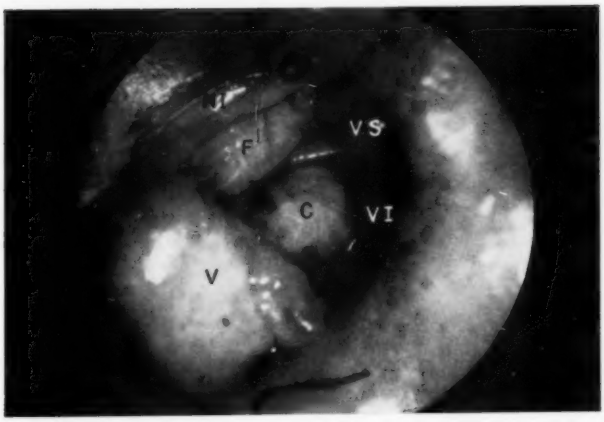

Fig. 7.—VIIth and VIIIth nerve complex at mouth of internal auditory meatus as seen in the monkey. V—central stump of cut vestibular nerve, VS—cut superior division of vestibular nerve, VI—cut inferior division of vestibular nerve, C— cochlear portion of VIIIth N., F—facial nerve, NI—nervus intermedius.

for parasympathetic fibres to reach the inner ear from the tympanic plexus.

3) Vagus nerve. It is also theoretically possible that preganglionic parasympathetic motor fibres from the dorsal vagal nucleus coursing in the vagus nerve may contribute to the tympanic nerve by the connection existing between jugular ganglion of the vagus and the petrous ganglion of the glossopharyngeal. If an anastomosis of autonomic fibres through this connection does exist, then parasympathetic fibres from the vagus may reach the inner ear in the same manner as described for the tympanic nerve.

4) Intermediate nerve. Preganglionic parasympathetic motor fibres from the superior salivatory nucleus run in the intermediate nerve. Connections of these fibres with the VIIIth nerve in the internal auditory canal, or via the fascicle between the geniculate ganglion and the VIIIth nerve, create a possibility for some of them to reach the inner ear. It has been shown that stimulation at the geniculate ganglion causes dilatation of arteries in the pia of the parietal region.[8]

Passe[9] has called attention to the possibility of parasympathetic fibres reaching the internal ear from the geniculate ganglion.

5) Cochlear portion of the VIIIth nerve. Finally, the possibility cannot be denied that parasympathetic motor fibres may run in the cochlear division of the VIIIth nerve directly from the brain stem to the internal ear. Lorente de No[27] has described what were considered to be vasomotor fibres leaving the cochlear nerve and passing into the connective tissue where they enveloped the blood vessels in grape-like endings. They may be derived, as he has suggested, from an anastomosis with the facial, or, as Rasmussen[21] has suggested, from the closely associated vestibulo-cochlear bundle of Oort, or even, as Winkler[28] has suggested, they may be visceral efferent fibres to the cochlea from the cochlear nuclei.

In order to prevent parasympathetic nerve impulses from reaching the inner ear by any of these routes, it is necessary then to section the following nerves: 1) vestibular, 2) glossopharyngeal, 3) vagus, 4) intermediate nerve, and 5) cochlear portion of the VIIIth nerve.

Sectioning of these nerves intracranially blocks all possible pathways for parasympathetic fibres to enter the ear. In doing so, however, the question arises: What effect occurs in the inner ear as a result of cutting the vestibular and cochlear nerves? There is considerable evidence by Kaida[29] and others that the VIIIth nerve may be sectioned with normal preservation of sensory structures, so long as the blood vessels that run with the nerve in the internal auditory meatus to supply the cochlea and vestibule are not injured. Therefore, we may cut all these nerves, including the cochlear and vestibular divisions of the VIIIth nerve to block any parasympathetic impulses from reaching the inner ear, and yet, if the blood supply to the inner ear remains uninjured, we can expect to find normal sensory elements in our sections of the experimental ears unless, of course, autonomic imbalance which has been brought about by the experiment alters the inner ear in some way.

TECHNIQUE

Denervation of the parasympathetic supply was carried out as follows. With the monkey lying in a face-down position, a U-shaped skin incision was made over the right occipital region and the resulting flap turned up. A similar muscle flap was cut and turned up. This exposed the bone over the right lobe of the cerebellum and the right mastoid cortex (Fig. 6A). By use of a dental drill and rongeurs bone was

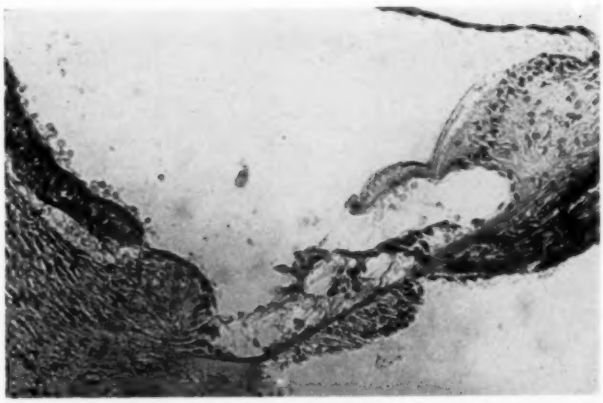

Fig. 8.—Monkey No. 148. Rt. showing organ of Corti, basal turn. This animal was permitted to live ten days after cutting the VIIIth nerve, accompanied by accidental injury probably involving the vascular supply to the basal turn only. The type of degeneration suggests oxygen deprivation.

removed to expose the dura over the cerebellar region, as well as the lateral and sigmoid sinuses. Incisions were then made in the dura along both sides of the sigmoid sinus (Fig. 6B). This converted the sigmoid sinus into a vein which could then be tied off above just below the superior petrosal sinus and below in the mastoid tip. Then, by clamping and coagulating the posterior emissary vein the sigmoid sinus could be excised (Fig. 6C). This offered a wider and better exposure to the posterior aspect of the temporal bone (Fig. 6D). The escape of spinal fluid, the removal of a small amount of the surface of the cerebellum with coagulation and suction, and the division of the flocculonodular lobe of the cerebellum increased the exposure in depth so that a fairly adequate view of the VIIIth nerve as well as the IXth, Xth, and XIth nerves at the jugular foramen could be obtained. Under magnification using the Lempert-Storz Lupe (6x magnification) and using a small sickle-shaped iridoclysis knife (Zeigler knife) the vestibular and cochlear nerves were divided at the internal auditory meatus (Fig. 7). With retraction of the two divided ends, the facial nerve and intermediate nerve could be seen. The intermediate nerve was then divided. Care was taken not to injure the internal auditory artery. Following this the IXth and Xth nerves

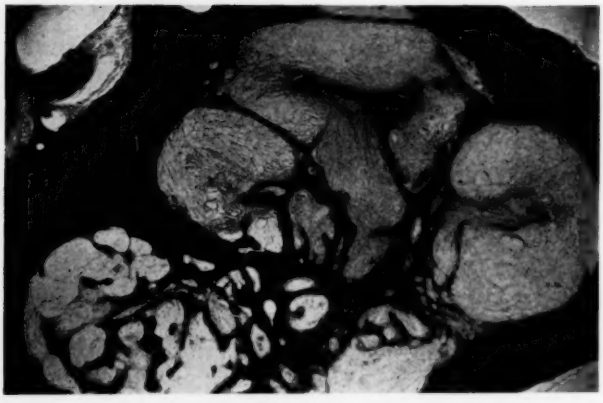

Fig. 9.—Monkey No. 146. Rt. Complete degeneration of sensory epithelium with fibrosis and new bone filling cochlear spaces. Sixty days postoperative. VIIIth nerve and internal auditory artery cut.

at the jugular foramen were divided. The small dead space was then filled with fibrin foam before closing the wound. The muscle flap was replaced and sutured to the neck muscles with surgical gut sutures and the skin flap closed tightly with interrupted silk sutures.

RESULTS

Of the seven monkeys used in this series of operations, four were sacrificed by the method described above for histological study.

Despite utmost care to avoid injury to the internal auditory artery during the operative procedures, this happened in some of the animals. The fact that injury to the vessel had occurred was easily determined by the appearance of bleeding in its vicinity during the process of cutting any of the three nerves, the vestibular, the cochlear, or the intermediate. This information was always recorded in the operative notes. Injury to the internal auditory artery, of course, eliminated the ear from any experimental consideration. Two of these ears are reported, nevertheless, as examples of damage in the internal ear brought about by interference with the blood supply, since it is a crucial point to be remembered that any denervation experiment of the inner ear is reliable only if the blood supply remains uninjured.

Fig. 10.—Monkey No. 149. Rt. The VIIIth nerve (as well as the nervus intermedius, IX, X) have been cut without injury to the internal auditory artery. The animal was permitted to live 60 days. The two stubs of the cut nerve are clearly seen at the entrance of the internal auditory meatus, separated by a layer of fibrous tissue, the proximal stub (VIII) displaced anteriorly. C. designates a portion of the cerebellum. Note degeneration of the VIIIth nerve in both directions; also excellent state of organ of Corti and maculae.

Monkey No. 148 was sacrificed after a period of ten days. The experimental ear (right ear) of this animal showed marked degeneration of the organ of Corti (Fig. 8). The greatest distortion appears in Hensen's cells and the outer sulcus cells. In the middle and apical coils the organ approaches the normal. This suggests damage to the vessels supplying the basal coil. The left ear (control ear) was normal.

Monkey No. 146 was sacrificed after a period of 60 days. The sensory structures in the cochlea and labyrinth were atrophied be-

yond recognition. They are replaced by dense fibrous tissue which shows evidence of progressive change to bone (Fig. 9). The left (control ear) was normal. The profound damage here suggests injury to the main trunk of the internal auditory artery.

When the blood supply remains uninjured, even though all the nervous connections to the ear (vestibular, cochlear, intermediate, glossopharyngeal and vagus) have been cut, the sensory elements remain normal. Postoperatively, the sympathetic nerve supply to the internal ear, of course, remains intact since it courses along the blood vessels, while the parasympathetic supply is completely denervated since it courses to the inner ear along the somatic nerves. The following histological description is of an ear which for a period of 60 days has been isolated from all of its nervous connections (including parasympathetic) and connected only to its blood supply and sympathetic nerves.

Monkey No. 149. Sacrificed after 60 days. The histological sections reveal the distal and central cut ends of the VIIIth nerve (Fig. 10). The distal end of the cochlear nerve shows degeneration proceeding backwards towards the cochlea and including the ganglion cells and dendritic processes. This is, of course, contrary to Waller's law which accounts only for the loss of a process separated from its cell body. Since Wittmaack's classical study,[30] however, this unusual type of degeneration in the VIIIth nerve has been well recognized. In Rosenthal's canal (Fig. 11) there are only a few ganglion cells (1/10 normal number). The visceral efferent fibres of Rasmussen's tract which have been described as corresponding precisely with the spiral fibres of the ganglion of Corti[22] show evidence of degeneration. If the destination of some of these fibres is the organ of Corti, degeneration of this tract appears to have had no effect on the sensory elements of this organ, for it appears normal in all respects (Fig. 12). The dendritic processes as evidenced by the tunnel fibres in the organ of Corti are absent in some areas and show evidences of degeneration in others. The hair cells appear normal throughout the cochlea. The spiral ligament and the striae vascularis are in good condition. Reissner's membrane is in normal position and there is no evidence of fluid changes in the cochlea or vestibule. The fibres of the vestibular nerve are atrophic while the maculae and cristae appear to be in excellent condition.

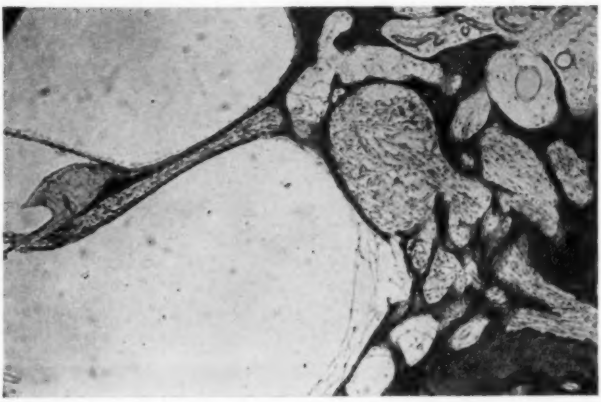

Fig. 11.—Monkey No. 149. Rt. Detail showing extensive atrophy of spiral ganglion cells and peripheral fibres in Rosenthal's canal of basal turn. Note also absence of spiral fibre bundles (Rasmussen's tract).

DISCUSSION

There can be no denying that if there is interference with the blood supply to the inner ear, there will be functional as well as structural changes in the inner ear. We have just seen evidence to this effect in the profound injury that occurs when the blood vessels are accidentally injured at operation. When the blood supply remains unimpaired, however, then complete denervation of the parasympathetic or the sympathetic nerve supply causes no damage to the sensory receptors or changes in the inner ear fluids.

Now why should this be the case in the inner ear? We know that the effect of autonomic imbalance can cause functional and structural changes in many areas. As a matter of fact, we know this effect is very marked in the middle ear. Lindsay[6] has described seeing under direct vision with the microscope the blood circulating in the smaller vessels in the middle ear mucosa come to a standstill in some areas under sympathetic stimulation.

I (J. R.) have verified this fact to my own satisfaction in the monkey. I anesthetized a monkey with nembutal, opened the mastoid, and removed both the bony and membranous posterior portion

Fig. 12.—Monkey No. 149. Rt. Detail showing perfect preservation of organ of Corti 60 days after operation which cut off all nervous connections (including parasympathetics) to the inner ear leaving it attached only to its blood supply and the sympathetic fibres travelling with the blood vessels. Note absence of tunnel fibres and presentation of normal hair cells.

of the external canal wall. I then made a long, wide fenestra of the horizontal semicircular canal. Using a dissecting microscope (25X), I was then able to view carefully the vessels in the major portion of the drum, the promontory of the middle ear, and in the perilymphatic space of the inner ear. I then did a sympathectomy as previously described in the denervation experiments to cut off all sympathetics to the inner ear. To create maximum imbalance in an animal under anesthesia, I then dropped pilocarpine in all areas every fifteen minutes to stimulate locally the parasympathetics. Observations were made through the dissecting microscope over a period of one hour. The vessels of the middle ear mucosa and the drum underwent a marked dilatation. I was unable to observe any change in the two small vessels running lengthwise along the endolymphatic labyrinth which had been in evidence since the beginning of the experiment. In contrast to the middle ear, there was no such reaction in the inner ear as has been described by Garnett Passe,[9] that is, gross dilatation of the blood vessels of the supporting trabeculae and of the surface of the membranous canal. On the contrary, the

membranous canal and the perilymphatic space remained remarkably clear.

Now what is the answer to these experimental differences to the reaction of the middle and inner ear vessels to autonomic influence? The answer is most likely to be found in the fact that the middle ear vessels are peripheral vessels and react to the influence of the autonomic nervous system as do the vessels in the skin. The internal auditory artery, on the other hand, is an intracranial vessel and reacts to autonomic influence in the same manner as other intracranial vessels.

There is considerable evidence to enlighten us on the mode of behavior of the intracranial vessels to vasomotor control. Forbes and Cobb[8] did a large series of experiments on more than 300 animals. They used a cranial window and microscope to observe and record the changing diameters of the vessels in the pia over the parietal cortex. They made the following points, that:

1) Stimulation of the cervical sympathetic nerve resulted consistently in contriction of arteries in the pia, occurring only on the same side of the head as the nerve stimulated.

2) The amount of constriction is small—an average narrowing of only eight per cent was observed.

3) It was observed consistently only with arteries larger than 50 micra in diameter.

4) No consistent change in calibre was seen in the smaller arterioles and capillaries.

5) Compared with the vasoconstriction observed in other organs, that in the brain is slight.

6) When the cervical sympathetic nerve is stimulated, arteries in the skin constrict ten times as much as those in the pia.

7) There was no evidence from experimental work to show that the cerebral vasomotor mechanism can cause the arteries to shut down sufficiently to cause ischemia.

CONCLUSIONS

These investigations show that a complete denervation of the sympathetic nerve supply to the inner ear produces no immediate alteration of any significance in the calibre of the labyrinthine vessels;

also, after complete denervation of either the sympathetic or parasympathetic supply to the inner ear, observations carried out over a period of ten days to two months fail to give any signs of damage to the sensory structures of the cochlea or labyrinth.

Therefore, we find no evidence to support the hypothesis that neurovascular disturbances in the inner ear can be brought about by autonomic imbalance.

Credit is given to the following for their assistance in the surgical procedures of this investigation: M. Desmond Cremin, F.R.C.S., England; Dr. Gottfriend F. Lindner, Germany; Dr. Franz Kroath, Austria.

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XCVIII

UNRECOGNIZED CHOLESTEATOSIS IN CHILDREN

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The subject of cholesteatosis or, as it is more generally termed, cholesteatoma, has given rise to much theorizing, not a little controversy and considerable confusion. The difference in terminology reflects the difference in opinion that exists concerning the cause, nature and growth of this pathologic process.

The term cholesteatoma has been challenged on the score that the primary or neoplasm theory of its origin has never been proved; the suffix, "oma," does, of course, imply neoplasm. Force of habit makes me prone to continue using the older and more familiar word, but I favor adopting the term cholesteatosis as a more accurate description of this process.

Although I concede that anlage may exist and, when activated by inflammation, can start the process, my clinical experience inclines me to agree, rather, with those who explain cholesteatosis on the basis of ingrowth by invagination or of metaplasia.

According to the metaplasia theory, a desquamative inflammatory reaction is set up in the epithelium of the middle ear, whence it extends. The ingrowth hypothesis is that the epithelium grows into the middle ear from the external auditory meatus through a marginal tympanic perforation; or ingrowth of epithelium may follow rupture of Shrapnell's membrane, by way of a perforation from whatever cause.

The cases of cholesteatosis in my experience have varied so widely in type that I, for one, cannot accept either the metaplasia or ingrowth theory to the exclusion of the other. Both theories are plausible; neither is conclusive. How cholesteatosis begins and develops in any given case depends perhaps on the predisposing factors

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From The Winthrop Foundation, Massachusetts Eye and Ear Infirmary, Boston,

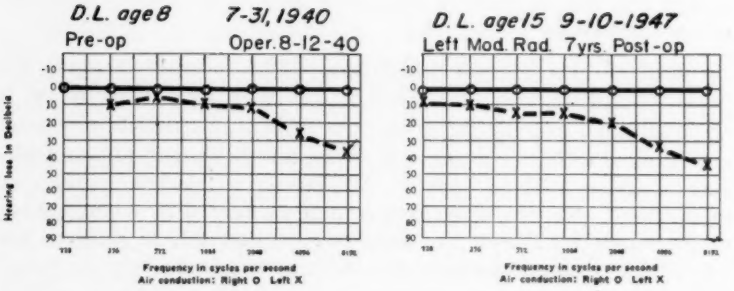
in that case. For that matter, the reason why cholesteatosis occurs in one and not in another individual may lie in the vulnerability of that individual to it.

But all this is pure speculation. And speculation about the cause of cholesteatosis, fruitful as it may ultimately prove to be, is an intellectual exercise for which the practicing otologist can spare only limited time and thought from the immediate and urgent problem of coping with its effects. Particularly is this true in the case of children. My own observations, now confirmed by a study made of Massachusetts Eye & Ear Infirmary case records of children ten years old or younger in whom cholesteatosis was found over the period 1937-52, give me a strong impression that the diagnosis is too seldom made early enough and adequate treatment too seldom carried out soon enough.

The 43 cases in children ten years old or younger (out of a total of 507 patients of all ages with cholesteatosis) afford one example after another of diagnosis made too late to save the hearing or of such temporizing treatment as repeated adenoidectomies, removals of polyps or granulations, and simple mastoidectomies. Even the simple mastoidectomy, which at least served the purpose of bringing to light an underlying cholesteatosis, is done much less often now that antibiotics are used to control the exacerbations of chronic suppuration. Thus cholesteatosis has an even better chance today of going undiscovered along its destructive path, invading and damaging beyond repair structures vital to the child's hearing.

A typical case is that of ten-year-old Gloria S., who for five years had been having a discharge from the left ear. A polyp in that ear was removed with no effect. Next, a tonsillectomy and adenoidectomy were done, followed by a second adenoidectomy. The discharge persisted, with several acute exacerbations. X-ray showed evidence of destruction in the left mastoid, with probable cholesteatosis, but not until four years later was surgery done. By that time a complete radical procedure had to be performed.

Reading between the lines of a record like this, one cannot help suspecting reluctance on the part of the surgeon to do surgery sooner —when a modified procedure might have been sufficient—and have to cope with the difficulties of postoperative management in such a young child. I appreciate the difficulties involved, difficulties that so often culminate in atresia or infection. But they are not insuper-


D.L. age 8
7-31, 1940
Pre-op
Oper. 8-12-40
Hearing loss in Decibels
Frequency in cycles per second
Air conduction: Right O Left X
D. L. age 15 9-10-1947
Left Mod. Rad. 7yrs. Post-op
Frequency in cycles per second
Air conduction: Right O Left X

able. Measures can be taken to reduce the risk of atresia or infection. The technique of temporal bone surgery can be modified to permit easy, painless access to the postoperative cavity of the young patient. And together with good illumination, magnification and the control of infection with the antibiotic drugs, these modifications of technique make temporal bone surgery as feasible in children as in adults.

What I want to stress is the importance of performing this surgery soon enough, while it is still possible to do a modified procedure, rather than wait until a complete radical has become necessary and considerable hearing thereby sacrificed.

An example of the excellent results one can achieve when cholesteatosis is recognized soon enough and surgery done early enough to permit a modified procedure is the case of eight-year-old David L. He was brought in with a story of painless, intermittent, malodorous discharge from the left ear. Examination showed a tiny perforation in Shrapnell's membrane. All landmarks were visible. Hearing for whisper and conversation was at 20 feet in both ears. A modified procedure was done and cholesteatosis found throughout the entire mastoid, enveloping but not yet having eroded the ossicles. These were retained in their normal position, in bas-relief, so to speak. Twelve years later, this boy's hearing was still excellent.

To achieve a result as rewarding as this, diagnosis must be made before the function of the ossicular chain has been disrupted. What

makes cholesteatosis difficult to recognize is the characteristically asymptomatic course of the disease. In the typical case, the only sign of trouble is aural discharge—scanty or profuse, continuous or with only brief remissions, and almost always malodorous. Sometimes there is not even a discharge. One mother's attention was drawn to the child's ear simply by the foul odor.

Pain is not usual, except as a pressure symptom or during exacerbations, usually brought on by upper respiratory infection or immersion. Even less common are headache, fever and chills, nausea and vomiting, or dizziness; these and such postaural signs as redness, tenderness and swelling develop only with mastoiditis and its complications.

Hearing, especially in children with epitympanic perforations, often remains normal for a long time or is only slightly impaired. Moreover, if the child is very young and only one ear is involved, hearing loss is not likely to be detected and may go unnoticed until he takes a routine hearing test on first attending school.

So unalarming is the picture, that the child is too often brought to the otologist only after the discharge has been going on for a long time. Physical findings vary from an apparently normal drum membrane, with just a little crusting in the region of Shrapnell's membrane and no visible perforation, to total destruction of Shrapnell's membrane, purulent or mucopurulent discharge and, possibly, flaky white debris. The normal tympanic landmarks may be obscured but still discernible. A pedunculated polyp may extrude through a small perforation or soft pulpy granulations be found which bleed easily on manipulation. Visible through the perforation may be cholesteatomatous material which can sometimes be drawn out with small cerumen hooks or by suction.

Shrapnell's and marginal perforations are the most characteristic, but it is fallacious reasoning to rule out cholesteatosis because the perforation found is central or anterior. Holmes[1] found 36 cases of anterior or central perforations in a series of 303 patients with cholesteatosis at the Massachusetts Eye and Ear Infirmary.

Although the clinical picture alone can provide the diagnosis, x-ray examination, with the patient in the fronto-occipital position, should be made. However, only when the cholesteatosis forms a mass of concentric shape, eroding bone sufficiently to create a well-

defined, smooth-walled cavity, does it provide a pathognomonic picture. But when it simply invades the antrum and mastoid, filling the pre-existing cellular spaces, with only decalcification or minimal destruction of bone, it gives no characteristic picture. This explains why even with expert interpretation, cholesteatosis may not be picked up by x-ray. A negative x-ray finding does not, therefore, rule out cholesteatosis. There is therefore no justification for delaying surgery until one has x-ray confirmation of the diagnosis. By this time there is sufficient bony destruction to show up on an x-ray film, the hearing may have been damaged beyond repair.

Given sufficient clinical evidence that cholesteatosis is present, with or without x-ray confirmation, and once a fair clinical trial has been given medical measures, one has no recourse but to carry out a modified radical mastoidectomy. It can be stated categorically that the longer the cholesteatosis is allowed to go on, the greater the eventual hearing loss.

Spontaneous cure of chronic suppurative otitis media with cholesteatosis is possible. But the instances of it are too infrequent and there is too much at stake to gamble on it.

Nor is simple mastoidectomy in children the answer, no matter how extensive the procedure. We are not dealing with disease of the bone alone, but with an epithelial accumulation. Until its source is eradicated, the accumulation will recur. To prevent this eventuality, the tissues of the epitympanum, antrum and mastoid must be exteriorized. To me, exteriorization means a complete exposure to view of these regions through a large external auditory orifice.

To permit easy, painless access to the cavity through a large external auditory canal orifice, I find the endaural incisions best. In children, the preauricular incision must be extended somewhat higher over the temporal fascia. The perichondrium and skin are elevated from the margin of the concha. Three to five millimeters of the free margin of the cartilage and the underlying soft tissues are removed. The reflected skin at the conchal margin is turned medialward over the edge of the cartilage, thus enlarging the orifice. The incisional gap between helix and tragus must be maintained, either by turning the skin edges medialward with a suture or by packing; otherwise, an obstructing constriction at the superior margin of the orifice will occur.

Since one can have no idea of the extent to which the cholesteatosis has involved the ossicles or invaded the tympanic recesses, one must approach the antrum and epitympanum gingerly. Only after inspection, under magnification, can one decide whether to leave the ossicles intact or remove them.

If, using the greatest care, one can remove the epithelial accumulation without breaking the ossicular chain, one can leave the ossicles in exposed position. Covering them with a Thiersch graft or with the canal-wall membrane only invites reaccumulation of epithelium. If the incus or head of the malleus is found diseased, it should be removed, thus exposing the epithympanum and permitting a complete and thorough removal of the epithelial lining and any supralabyrinthine cells.

A thin, split-thickness Thiersch graft is carefully placed on the medial wall of the epitympanum, sealing the middle-ear space. The inferior margin of the graft is so placed that a millimeter or so overhangs the anterior and posterior folds of the membrana tympani. The graft is more likely to take at the drum margin if the anterior and posterior folds are freshened. Sealing the tympanum will maintain or even improve the hearing.

In cases with anterior, central or posterior marginal perforations, should the tympanum be free of disease, one leaves the drum membrane and follows the procedure described. In cases of posterior marginal perforation, the incus is usually absent or so diseased that it must be removed. In such an event, the head and neck of the malleus becomes useless and should be removed also; its removal opens the epitympanic space for thorough exenteration. In cases of marginal perforation, the membrana tympani anterior and inferior to the perforation is often adherent to the medial wall. In these instances I leave the tympanum undisturbed.

The difficulties of after-care in children can be reduced by skin-grafting. A split-thickness, sectional Thiersch graft is used; a small incision in its center permits escape of secretions from between graft and bone. Polymyxin B powder is dusted over the surface of the graft, and small pieces of moistened gelfoam are used to hold the graft in position against the bone; to exert greater pressure, small balls of paraffin mesh are placed over the gelfoam.

The principles of temporal bone surgery—modified and radical—have undergone little fundamental change since the twenties. But

better illumination and magnification, specially designed instruments, and the steady advances made in technique, together with the boon of the antibiotic drugs, have combined to make this kind of surgery feasible in the very young, giving the otologist of today every opportunity to save the hearing of countless children.

CASES

There is little point in giving in detail all of the 43 cases in the series studied, since so many merely reiterate the story told by the two case records summarized above and those that follow.

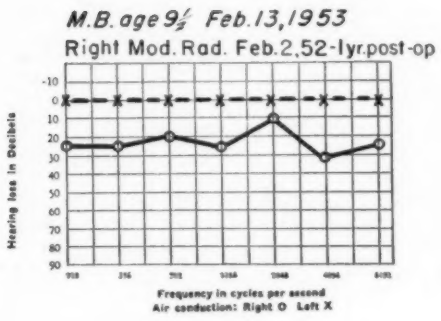
Case 1, an example of cholesteatosis in a pneumatic mastoid, with the ossicular chain intact: S. R., 9 years of age, had chronic suppuration of the right ear, without pain, of three years' duration. Examination showed malodorous discharge coming from an anterior perforation of Shrapnell's membrane. X-ray examination revealed fully developed, pneumatic mastoids, the right smaller than the left. There was no evidence that the antrum was enlarged.

A modified radical procedure was carried out on the right. Cholesteatosis was found to have invaded all mastoid cells, with out cavity formation. The head of the malleus and the incus were embedded in granulations, which were carefully removed with dental-spoon excavators, without disrupting the articulation. The epithelial matrix behind the ossicles could not be removed. The mastoid cavity and tegmen were skin-grafted. The ossicles were left exposed, in bas-relief.

This child, owing to long neglect, was markedly underdeveloped and undernourished and because of personality difficulties so uncooperative that a reliable audiogram could not be obtained; it was determined, however, that she could hear moderate conversation in the right ear at 15 feet.

Case 2, an example of cholesteatosis in an underdeveloped mastoid requiring removal of malleus and incus, with preservation of good hearing:

M. B., 8 years of age, was symptomless until an episode of pain, lasting one day, occurred in her right ear. Examination a week later showed scanty, malodorous discharge and slight, increased vascularity of the membrana tympani. No perforation was noted, but a small granuloma in the lateral aspect of the posterior-superior canal wall was seen.



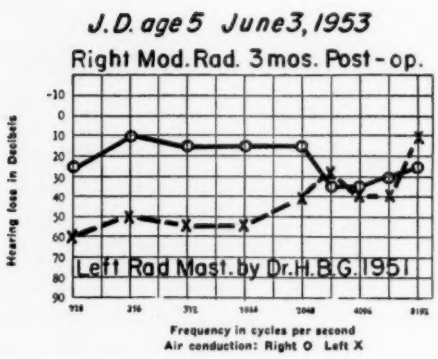
According to the mother, a physician who examined the child at the age of six months had said her ears were "abscessed."

X-ray films indicated that there was no pneumatization in either mastoid, but a large area of destruction on the right was suspected; repeated x-ray examination a week later confirmed this finding. A hearing test showed a negative Rinné on the right. According to the examining physician, normal conversational voice was down to four feet on the right; on the left, hearing was normal.

When the child was referred for surgery, examination confirmed the previous findings; this time a small probe could be passed to a considerable depth through the granuloma into the mastoid, indicating erosion of the mastoid cortex.

A modified radical procedure was carried out. The mastoid was found to have been entirely destroyed by the cholesteatosis, which extended into the middle-ear space. The incus and head of the malleus were eroded; they were removed, thus permitting good inspection of the middle ear, which was free of disease. Despite disruption of the ossicular chain, the hearing in the operated ear averages 20 decibels in the speech frequencies.

Case 3, an example of bilateral cholesteatosis where hearing must be maintained because of previous radical procedure with considerable hearing loss: A complete radical mastoidectomy had apparently been found necessary, because of extensive cholesteatosis, in two-



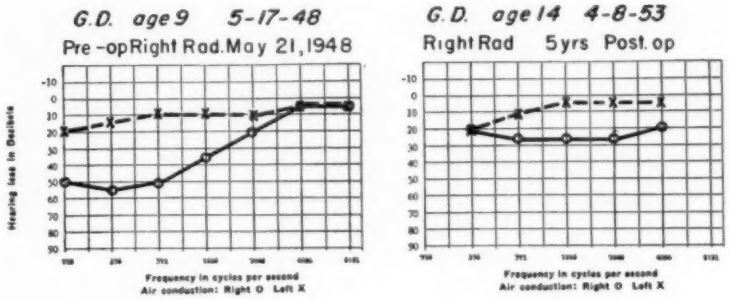
year-old J.D. At the age of four, after one day of pain in the right ear, it began to discharge. Examination revealed a small perforation in Shrapnell's membrane in the right ear; all landmarks of the membrana tympani were visible. X-ray examination showed a clean postoperative cavity on the left and a large cholesteatosis cavity on the right, no cells remaining.

A modified endaural radical procedure was done. The entire mastoid and epitympanic space was found displaced by cholesteatosis. The incus and head of the malleus were eroded and had to be removed. The cavity was skin-grafted.

This child, now undergoing aural rehabilitation, attends grade school without benefit of hearing aid.

Case 4, G. D., an example of good hearing, despite chronic suppuration with cholesteatosis: This nine-year-old boy developed, following swimming, a spontaneous discharge from the right ear, without pain. A year later, x-ray examination showed cholesteatosis of the right mastoid. Physical findings were a markedly distorted membrana tympani, with malodorous discharge coming from an anterior perforation in Shrapnell's membrane. According to the hospital admission note, conversation in that ear was at 20 feet.

At operation, the cholesteatosis was found to have considerably enlarged the antrum and destroyed the incus and malleus. In view

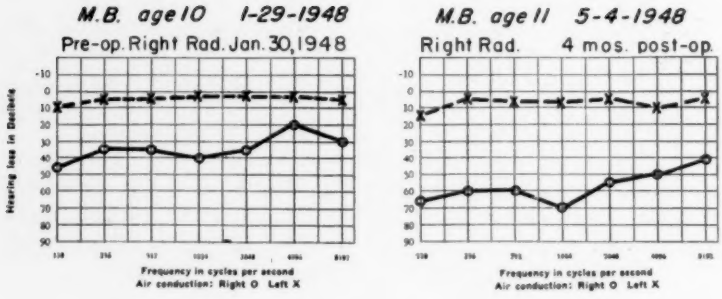


of the good hearing, the membrana tympani—although grossly abnormal in appearance—was not removed, excellent judgment in the light of the most recent audiogram in this boy.

Case 5, R. D., an example of bilateral chronic suppuration with cholesteatosis in only one ear. This four-year-old girl was seen in the Out-Patients' Department on July 17, 1943 with a history of chronic suppuration since the age of six months. Examination showed bilateral, large central perforations with foul discharge. X-ray studies showed both mastoids sclerosed, with enlargement of the antrum on the left, probably by cholesteatosis.

An acute exacerbation, with pain in the right ear again brought the child to the Out-Patients' Department in November, 1943, and she was admitted on the 13th of that month for a right simple mastoidectomy. At this time an audiogram, which considering the age of this child can be regarded only as an approximate measure of her hearing loss, showed a loss of 40 decibels on the left, with conversation at five feet; on the right, hearing loss averaged 60 decibels, with conversation at three feet. At operation, considerable destruction, but no cholesteatosis, was found.

On January 7, 1944, an x-ray finding of an enlarged antrum by what appeared to be cholesteatosis made it appear advisable to operate on the left ear. Cholesteatosis was found practically filling the entire mastoid, antrum and middle-ear cavity. The mucosa of the middle ear was left undisturbed. Only the cholesteatosis and the diseased ossicles were removed, probably accounting for the fact that


M.B. age 10 1-29-1948
Pre-op. Right Rad. Jan. 30, 1948
Hearing loss in Decibels
Frequency in cycles per second
Air conduction: Right O Left X
M.B. age 11 5-4-1948
Right Rad. 4 mos. post-op.
Frequency in cycles per second
Air conduction: Right O Left X

today the patient states (in a telephone report, declining to come in for examination) that her hearing is adequate for her classroom work; she does not wear a hearing aid.

Case 6, J. Y., illustrates unrecognized cholesteatosis which, judging from its extent, must have developed over a much longer period than the history would account for. This boy was first seen at the age of three for a discharge from the right ear developing after only one night of pain. His physician described the drum membrane as appearing "whitish" in color and noted an anterior perforation in Shrapnell's membrane, from which a polyp protruded. The child was given penicillin and the polyp removed. Next a routine tonsillectomy-adenoidectomy was done, and the discharge stopped after a week; but the drum membrane remained thickened and white. Within five months a polyp had to be removed again. Hearing in the right ear was down to 30 decibels in the speech frequencies. X-ray examination, with the patient only in the lateral, not the fronto-occipital position, did not show the characteristic cholesteatosis cavity. Three months later another polyp was removed. The child was then referred for a radical operation.

X-ray reexamination, in the fronto-occipital position, now showed a large cholesteatosis cavity in a small, underdeveloped right mastoid. Although a modified procedure had been intended, it became necessary to do a complete radical, cholesteatosis having been found to involve the entire mastoid, middle ear and eustachian tube.

An important finding at operation was the presence of cholesteatosis in the middle-ear cavity which the physician apparently saw though the membrana tympani, accounting for its "whitish" appearance.

No postoperative report of hearing has been received from the referring physician.

Case 7. M. B., a classic example of cholesteatosis growing to enormous size, despite a silent course, until structures vital to hearing have been destroyed and a complete radical made necessary with ultimate marked hearing loss. Had the cholesteatosis been recognized sooner the destruction might have been avoided.

In this ten-year-old girl, only a slight odor directed the mother's attention to the right ear. Not even the typical discharge was present in this case. Five months later, local examination showed only a foul crust in Shrapnell's area. X-ray examination revealed an enlarged antrum on the right. A hearing test brought out a 35 decibel loss on the right.

On operation a huge cholesteatosis mass was found to have extended into the middle ear, necessitating complete radical mastoidectomy.

The appearance of the drum membrane, with a tiny perforation of Shrapnell's, suggests that a modified procedure could have sufficed. Unfortunately, many surgeons fail to recognize that the presence of cholesteatosis in the middle-ear space does not necessarily mean that it originated there. It may signify nothing more than extension from the epitympanum, the process having followed the line of least resistance. Frequently this occurs without injuring the middle-ear mucosa and the cholesteatosis can be removed as part of a modified procedure.

243 CHARLES ST.

REFERENCE

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XCIX

INTRAVENOUS PROCAINE IN THE TREATMENT OF MÉNIÈRE'S DISEASE

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NEW YORK, N. Y.

To assess any method of management for Ménière's disease[1] is a very difficult task, even if the symptom complex is clear cut, that is, if there are intermittent paroyxsmal attacks of vertigo, with nausea and vomiting, with tinnitus and some deafness in one or both ears. As far as could be made out, from an analysis of our cases of true Ménière's disease, with a follow-up of at least six months (most were over a year) some improvement almost invariably follows careful workup, and especially hospitalization, no matter what treatment is used. This paradox poses a real problem in the assessing of any condition, which often manifests long free intervals without striking symptoms.

Soon after we began experimenting with intravenous procaine some four years ago, it became apparent that the drug, although useful, was no infallible panacea for Ménière's disease. A glance, however, at the accompanying tables shows that intravenous procaine especially when used in conjunction with psychotherapy and nicotinic acid compares very favorably with other well-known treatments for the endolymphatic hydrops which is known to be the pathologic basis of the disease.[2] In our hands it was much better than intravenous histamine where only one case of improvement occurred out of nine cases and it was also much better than decompression of the endolymphatic sac after Portmann.[3] With the latter out of eight cases no improvement was present. The more heroic methods of labyrinth destruction, by the method of Day[4] or with streptomycin,[5] produce more permanent and lasting effects on the

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TABLE I.
SUMMARY OF 35 PATIENTS WHO RECEIVED I.V. PROCAINE

	IMPROVED	UNIMPROVED
Deafness	11 (3)	24
Tinnitus	13 (5)	22
Vertigo	27 (8)	8

Figures in parentheses are number of cases with complete relief.

TABLE II.
SUMMARY OF 21 DAY OPERATIONS.

	IMPROVED	UNIMPROVED
Deafness	0	21
Tinnitus	9 (3)	12
Vertigo	20 (14)	1

Figures in parentheses are number of cases with complete relief.

vertigo of severe cases, but they have more side reactions than the procaine treatment (Table I and II).

The treatment for true Ménière's disease, depends upon the violence of the symptoms. If they are very severe, prolonged and unilateral, the coagulation surgery of Day is undoubtedly the treatment of choice. When the disease is bilateral, or when a coagulation has been done and the new paroxysmal attacks occur from the other side, streptomycin therapy is probably indicated.[5] In the milder cases, strong reassurances, nicotinic acid by mouth in sufficient quan-

tities to produce a flushing effect, 1/150 gr of hyoscine hydrobromide under the tongue to abort rare and acute attacks and, in slightly less severe cases, dramamine and benadryl (I prefer the latter) are adequate. In addition a moderately restricted salt and fluid regime and abstinence from smoking seem to be helpful.

It has been our practice in the Ear, Nose and Throat Department of the Columbia-Presbyterian Medical Center for the past four years, if nicotinic acid by mouth, benadryl and hyoscine under the tongue do not work to admit the patient for intravenous procaine therapy. Recently, we have been subjecting all hospital admissions and as many out-patients as we could to psychological work-ups, and many to psychotherapy of a common-sense nature.[6]

It can be seen that our therapeutic approach is very little different from that advocated (incidentally, without collaboration) for the last few years by Dr. Jerome Hilger of Minneapolis.[7] With the exception of the procaine treatment, it is very little different from that which is inferentially recommended by Dr. H. B. Williams in his recent book,[8] and those of other clinics. The communication at hand is primarily concerned with the physiological effects of procaine, and the remainder of the paper will be devoted to that phase of the subject.

It has been reported in the discussion of my father's paper on "Sudden Deafness" in San Francisco in 1950,[9] and in a paper on a similar subject before the 25th anniversary meeting of the New York League for the Hard of Hearing, in April 1950,[10] that it is our belief that the symptoms of Ménière's disease and ultimately the pathology is due to a blockage of the circulation in the labyrinth by the aggregates of red blood cells, which have been named by Dr. Melvin H. Knisely, "blood sludge"[11] (Fig. 1). There are undoubtedly accessory phenomena.

While studying the phenomenon of "blood sludge" in the laboratory, it was found that it could be produced locally by cervical sympathetic stimulation, and by adrenalin, and that the aggregates so produced tended to stop in areas where there had been the slightest injury.[12] It was also found that intravenous procaine in animals seemed to break up red cell aggregates. The patients with Ménière's disease were found to manifest considerably more than the average in vivo agglutination of red cells, before and after attacks. Accord-

ingly, in 1949, the use of intravenous procaine hydrochloride, 1/10 of 1 per cent in 500 cc of glucose was assayed in severe Ménière's disease. Nowadays we divide this into two doses.

On examination of the conjunctiva vessels during the administration of intravenous procaine, it was found that the red cells travelled very much faster than normal, both in the human and animals starting 10 to 15 seconds after the onset of the infusion if it was given rapidly. We use an 18-gauge needle; a 250 cc infusion is given twice a day. Each infusion lasts an average of ten minutes.

To substantiate further the rationale of giving intravenous procaine to a patient with Ménière's disease, it was found that concomitant with the increased speed of circulation in the conjunctival vessels, the patients often volunteered the information that their tinnitus was either markedly diminished or completely disappeared during the infusion.

A few patients, however, claimed that their tinnitus increased during the infusion. Many of these experienced diminution a half hour to an hour and a half after cessation of the infusion. When the tinnitus was improved by the infusion, it could be brought back almost immediately by turning off the flow, and then could be made to disappear again by allowing the intravenous flow to continue. It was thought at first that the disappearance of tinnitus might be due to suggestion, but many patients, thinking that the infusion was entirely for their dizzy spells, volunteered the information that the tinnitus improved without any possibility of psychic suggestion having been apparent. A few patients felt that their deafness improved during the infusion, and several remarked that sounds contained a bell-like quality. Attempts at audiometrics evaluation in three cases failed because the patients had difficulty concentrating during the infusion. There were often annoying but not serious other symptoms during the infusion.

On study of the literature it was found that temporary cessation of tinnitus through the use of procaine has been previously reported by Barany,[13] who injected the highly vascular nasal septum or the turbinates, and by Lewy[14] who used the drug intravenously.

Symptoms experienced during administration of 250 cc of 0.1 per cent procaine in 5 per cent glucose diluted with water given in 8-10 minutes as noted by Dr. Claude L. Pennington of our service

were as follows: (1) dry mouth, (2) difficulty in swallowing, (3) feeling of weakness, (4) decreased tinnitus, (5) voices became clearer, (6) voices assume a 'tinny' quality and may sound far away, (7) a feeling of drowsiness, (8) stiffness all over, (9) sweating palms, (10) slight flushing and feeling of heat in the face, (11) throbbing sensations in lower extremities which gradually pass cephalid and settles in the abdomen, (12) hypalgesia in extremities which may also be present at end of infusion over entire body to lesser extent, (13) increased tinnitus, (14) pulse becomes slower, (15) blood pressure drops about ten points. The untoward reactions were: general morbilliform rash, angioneurotic edema, convulsions (this patient also had convulsions when given normal saline), precordial pain, and palpitations after the infusion.

The history of sensitivity to procaine was only elicited in one case. This patient showed a marked skin reaction to procaine, both in the forearm and in the back, when a lumbar puncture was performed. It was deemed unwise to give this patient intravenous procaine. It is well-known however, that skin tests to drugs are not reliable in assessing a patient's sensitivity to drugs. Graubard[15] on over four thousand patients claimed that no untoward reactions resulted. It is the feeling of most authors, who have worked with intravenous procaine that the fear of its use has been engendered by the accidents that occur when it is mixed with adrenalin.

Encouraged by the sign (change in tinnitus) that procaine was indeed having an effect on the ear, concomitant with changes in the capillaries that were available for viewing in the conjunctiva, it was thought wise to find out with multiple photographs exactly what the procaine did to the blood vessels both in humans and in animals (Figs. 3 and 4).

It was found that a slight dilatation occurred in the venules and capillaries, and the conjunctival tissues became clearer and easier to photograph as the infusion progressed (Fig. 5). This lasts for a considerable period after the infusion is finished. Photographs with a flash at 1/5000 of a second, did not completely settle the point as to whether the aggregates of blood cells were broken up or whether their speed passing through the vessels made the sludging non-apparent. It appears that at least some of the aggregates are broken up. At first, it was thought that increased pulse rate or increased blood pressure might account for the increased speed. Incidentally, while

TABLE III.
BALLISTOCARDIOGRAPH RECORD WITH PROCAINE INFUSION. 500 CC 0.1%. A VERY APPREHENSIVE PATIENT.

P. T. Age 36	H.R.	S.V.	C.O.	B.P.
control	79	68	5.5	118/80
needle in vein	87	104	9.0	132/84
after 2″	94	128	12.0	132/84
after 10″	80	157	12.6	122/76
9″ after stop	74	85	6.3	118/76

the procaine is going in and for several minutes afterwards, there are fewer areas where vasomotion is manifested by sluggish circulation in the capillary beds of the conjunctiva. Rises in blood pressure, if they occur, are rarely over ten mm of mercury. Even in patients who were very apprehensive pulse rate only went up 10 to 15 beats per second. This does not account for the tremendous speed of flow seen in nearly all vessels.

Various studies have now shown that the increased speed in blood flow is due to increased cardiac output. Ballistocardiograph studies on four patients first indicated this increased cardiac output, as shown in the accompanying tables, which were done by Dr. John L. Nickerson (Table III). Then control studies by Zia Javid using the Frick dye method revealed a similar situation in dogs.[17]

Incidentally, the hematocrit changed from 40 per cent to 50 per cent in at least one dog, although only four cc of fluid was given with the procaine, so as to eliminate the possibility of the increased circulating blood volume, due to the fluid of the infusion. A study of Table 5 shows that the increased cardiac output is not commensurate with the volume of fluid given.

Lastly, radioactive sodium studies (three done by Dr. Hugh Fitzpatrick and one by Dr. Samuel Powers of the Department of Surgery) also showed an increased cardiac output of about the same

TABLE IV.
RADIOACTIVE SODIUM MEASURE OF CARDIAC OUTPUT FROM PROCAINE INFUSION. 250 CC 0.1%.

Control	5.2 liter per min.
5″ after start	7.2 liter
10″ after stop	5.8 liter
20″ after stop	4.8 liter

magnitude as found with the ballistocardiogram, and in the dye studies of dogs (Table IV).

Over a period of years the rationale for the use of procaine has been built up as follows: it is felt that increased speed of circulation improved the circulation in the inner ear, and, if some aggregates of red cells were stuck in some of the smaller vessels, but were loose enough to be dislodged, that the local situation might be improved in the ear. After trying procaine alone with only moderate success, we have taken the suggestion of Dr. Jerome Hilger,[7] and added nicotinic acid to the procaine, but we use it by mouth to prolong the effect. Recently, we have gone one step further and started to give heparin and dicumerol during the treatment, hoping to break up the sticky substance which is presumed to keep the sludge together in large masses of red cells, and make it stick to vessel walls. A word of caution—hematomas are common when using anticoagulant therapy and procaine infusion with it and will not be recommended until more experience has been forthcoming.

It is hypothecated that a regime of procaine, nicotinic acid and possibly anticoagulants will help in Ménière's disease, provided that blockage in the blood vessels of the labyrinth is not too severe, or too permanent. Intermittent blockage such as may be seen in the active phases of Ménière's disease can be due either to spasm, to a lump of "sludged" blood which is so large that it can not pass through the funnel of some pre-capillary sphincter, or a metarteriole in a vital area, or to both lumping and spasm. The latter is most probable. If a blockage lasts long enough, it produces an actual thrombosis. It is felt that the stoppage of the "sludge" in the vascular

tree of the labyrinth may have an anatomical cause, such as a violent bend in the vessel, or be due to hypersensitization of the area by a previous injury. This could be by acoustic trauma or by a blow on the head or even by infection or allergy.[12] "Sludging" is known to occur with severe psychic stimulation, with infections, and with direct trauma. Masses of agglutinated blood can be very large under such circumstances. The larger the mass of the circulating aggragates the more likely a lump is to catch in the fine sieve of the labyrinth vascular tree and the less likely it is to be pushed on by any method, whether the vessels are dilated at the same time or not.

Finally, there is no question in our minds that there is a stress factor present in almost, if not all, cases of Ménière's disease.[18] Whether this stress factor is fatigue, infection or emotional it may recur, in which case re-treatment with vasodilators, and procaine intravenously may be indicated. In our most successful case each time that the patient felt a new attack coming on, which was about every five days, she took another infusion of procaine. In the long run her improvement in hearing was most remarkable (Fig. 9). There were many psychic traumata in her case, and she received considerable psychotherapy. For instance, she was advised to go away from her home, and to leave her rather exacting job. She found the change intolerable, however, and returned to both of them, but she is now very much better adjusted. She has learned, perhaps, to live with the stresses which used to bother her. Unquestionably, there were many factors in her improvement, of which procaine was only one. But this medication because of its immediate pharmacological help gave her hope and also indicated to us that the symptoms were still reversible.

We now have one patient, who instead of taking intravenous procaine when she feels an attack coming on, takes one gram of procaine hydrochloride by mouth, and this with her has very much the same effect as intravenous procaine (Fig. 10). Two other cases in which procaine by mouth has been tried have been unsuccessful.

Some of the effects of intravenous procaine may be central, according to Olson.[19] Graubard,[15] who perhaps, has had the most experience with the drug, believes that it may eliminate the reflex arcs which hold the peripheral sphincters, as well as other parts of the arterial tree in spasm. As soon as a spasm is relieved, vasomotion returns, anoxia is reversed, abnormal capillary permeability is elim-

inated, and the tissues can return to their normal state of intermittent vasomotion, in his opinion.

This looks as if it might be a reasonable theory, when one watches the capillary circulation in the conjunctiva of human beings, and of animals. If it is correct one would not expect a dramatic, immediate relief of such symptoms as vertigo and deafness. One would also not expect the symptoms to remain absent, if the factors which caused the small blood vessel spasm and the sludging were allowed to operate again. Interestingly enough, intravenous procaine tends to collect in injured tissues,[15] so it may have more action on diseased tissues than on normal tissues.

It is my belief that intravenous procaine helps in the relief of spasm of the vessels in the labyrinth, in spite of the fact that sympathetic fibers have not been histologically demonstrated within the labyinth. Actually even with complete severance of nerve supply there are changes in the capillaris attributed by Cannon to tissue sympathin.[20] I find it difficult to believe that vasomotor and pathological spasms can not occur in the labyrinth as they do everywhere else in the body. Relief of spasm, increased speed of blood flow, washing out of accumulated "blood sludge," and then finally relief of edema and anoxia I believe to be a reasonable explanation for the effect of procaine on the ear, for it certainly occurs in the conjunctiva and in the mesentery. We are still trying to devise means of seeing such mechanisms in the inner ear. But access to the inner ear is difficult, and the slightest injury produces the very bad effects which we are discussing. When and if an episode of the syndrome is due to hemorrhage or a well fixed embolism or thrombosis, procaine could hardly have any direct effect on them. Even here, however, it might partially alleviate secondary edema by improving circulation and thus relieving symptoms.

To recapitulate, I feel that the primary trigger factor in Ménière's disease is stress[21] and that the symptoms usually occur after long continued aggravation in a susceptible individual. Therefore, no one medication such as intravenous procaine, will ever be a panacea for Ménière's disease any more than it will be for any other psychosomatic disease. I do believe that it is a valuable tool to alleviate the symptoms of the moment and to obtain the confidence of the patient, so that proper psychiatric measures can be taken. If this is successful, new

occurrences of stress may not again precipitate the violent manifestations of the disease.

630 W. 168TH ST.

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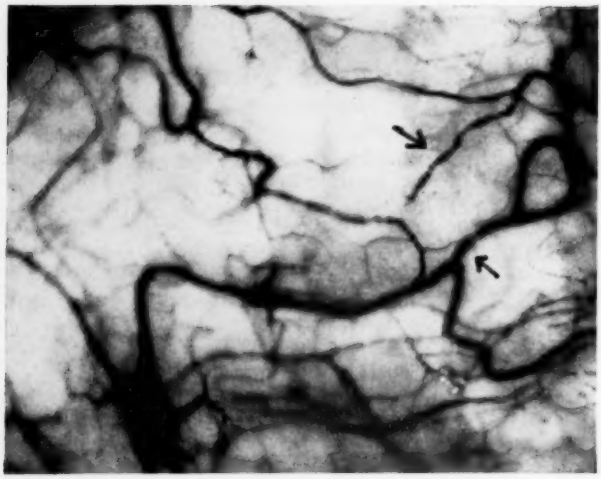

Fig. 1.—2.5 x 2 mm of the conjunctiva of a patient with Ménière's disease treated with 1/10 of 1 per cent intravenous procaine 250 cc in ten minutes. Note lumping of blood (arrow) before infusion was started.

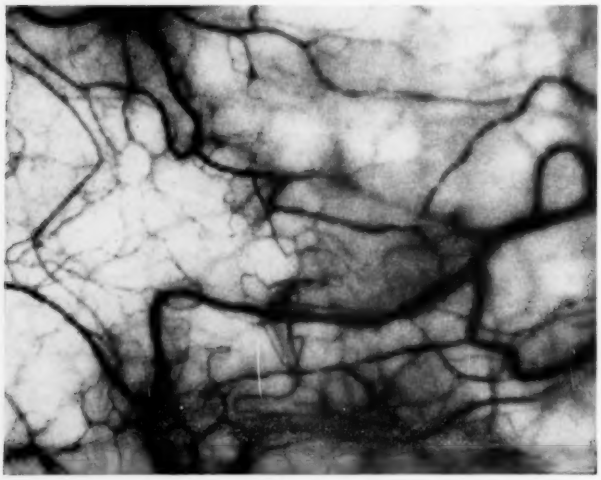

Fig. 2.—Two minutes after infusion was started. Note beginning dilation of vessels.

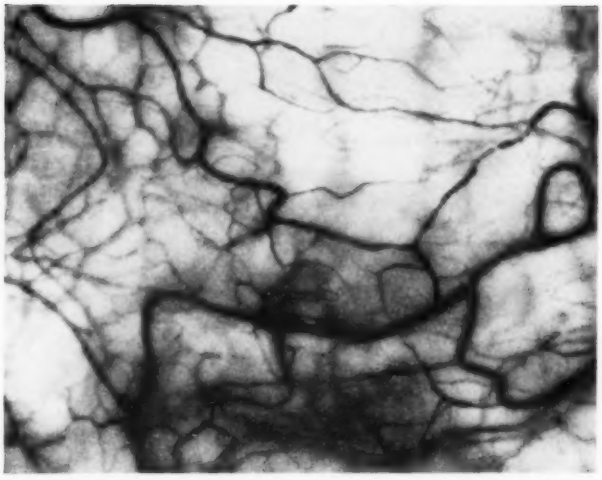

Fig. 3.—Five minutes after start of infusion. Note reduction of lumping.

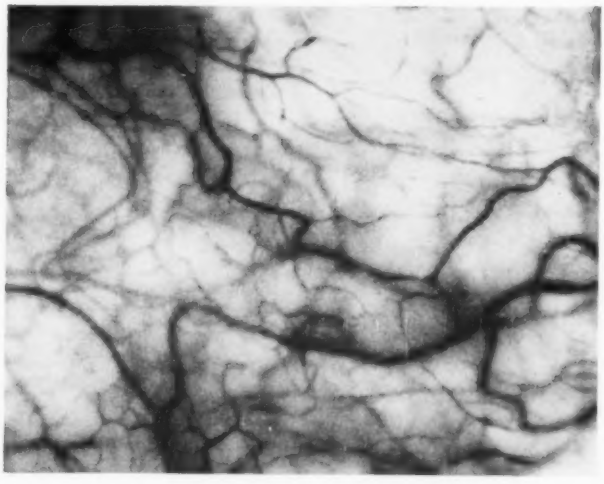

Fig. 4.—Nine minutes after start of infusion.

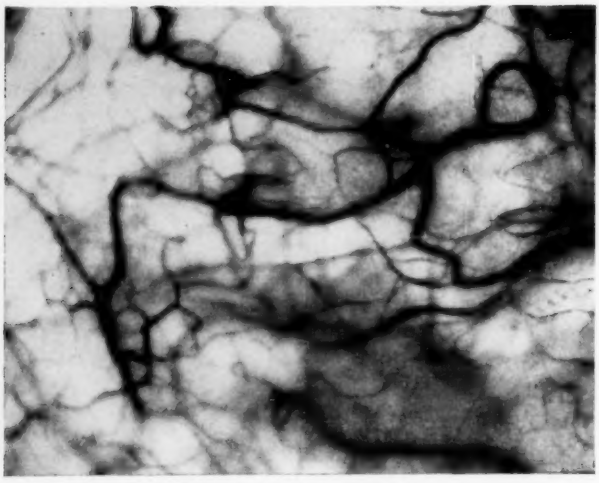

Fig. 5.—Compare with Fig. 1. Two minutes after infusion has been finished.

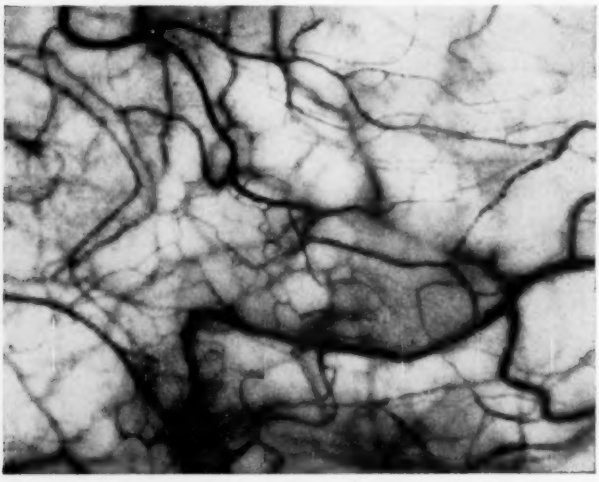

Fig. 6.—Seven minutes after infusion has been finished. Note return of lumping but clearing of tissue.

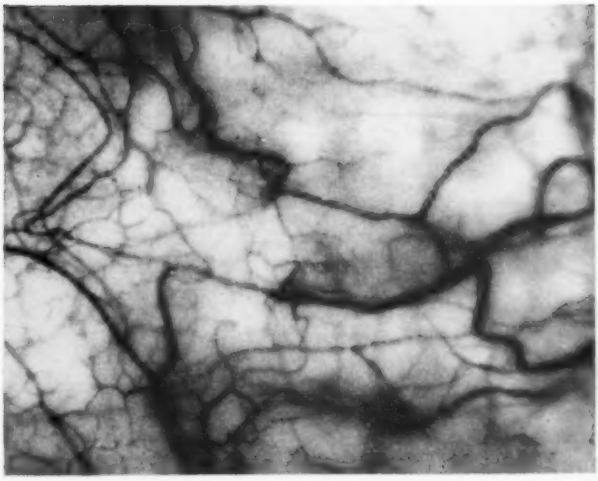

Fig. 7.—Seventeen minutes after end of infusion.

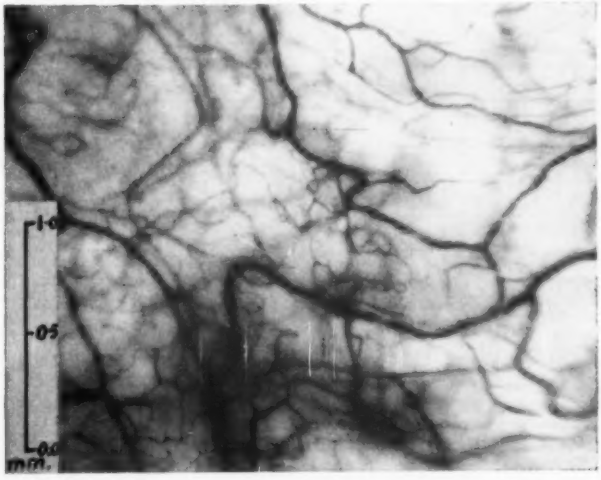

Fig. 8.—Twenty-eight minutes after end of infusion. Note that interstitial tissue is still clear.

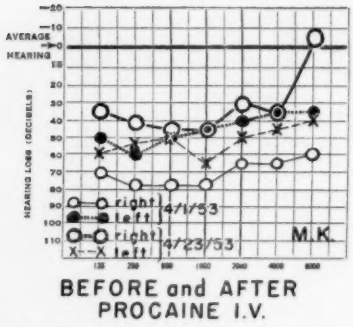

Fig. 9.—Audiograms of a patient with Ménière's disease. Both ears improved over a period of months on intravenous procaine therapy. Note that bone conduction designated by brackets improved. Arrow indicates that bone conduction for given frequency was not heard at the time of the audiogram (3/16/50). Hearing for the right ear had not changed significantly by 6/9/50, so the readings for this date are not outlined in the graph.

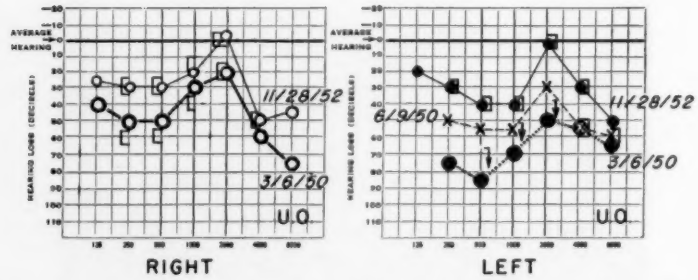

Fig. 10.—Salvage of hearing in patient with sudden deafness and Ménière's disease symptoms of three weeks' duration. Patient received intravenous procaine and also procaine hydrochloride 1 gm t.i.d. by mouth with cessation of vertigo and some improvement of hearing. This was still present 5/14/53 as was tinnitus. (The patient four years before had had a similar sudden deafness in the left ear, but there was no improvement after this episode in spite of antihistamine and nicotinic acid therapy.) Note that there was little, if any, change in the left ear with procaine therapy four years later.

C

INNER EAR PATHOLOGY FOLLOWING MATERNAL RUBELLA

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The relation of rubella in the first three months of pregnancy to certain congenital defects was first described by Gregg[1] of Australia in 1941. The abnormalities commonly found are congenital cataracts, patent ductus arteriosus and other cardio-vascular defects, deaf-mutism, microcephaly, dental defects and a general stunting of growth and development.

The occurrence of deaf-mutism was first described by Swan and others[2] in 1943.

Carruthers[3] in 1945 reported that in 147 cases of congenital defects following maternal rubella, observed by himself and his colleagues, 116 showed severe deafness. In the same paper he presented the first report on the pathological findings in the inner ear.

Goodhill[4] as a result of a questionnaire sent to mothers of 904 profoundly deafened children, found maternal rubella to have been "the potential cause of deafness" in 25 per cent of cases.

Hiller[5] in 1950 reported on 32 cases of rubella deafness among 42 congenitally deaf children in Tasmania.

From the Division of Otolaryngology of the University of Chicago.

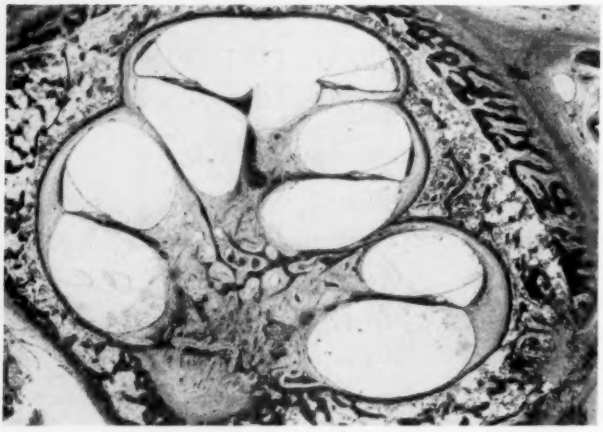

Fig. 1, Case 3.—Magnification X 23 of mid-modiolar section of the right ear. 20-22 week fetus. Length 28.5 cm. The stria vascularis and Reissner's membrane are normal. The peripheral neuron is incompletely developed at this stage. There is incomplete differentiation of Corti's organ and the tectorial membrane. Differentiation is greatest in the basal coil, less in the middle coil and least in the apical coil (see Figs. 2, 3 and 4).

The high percentage of deaf-mutism found following the Australian epidemics is in contrast to the much lower percentage reported by Goodhill and the still lower figures of 2-3 per cent reported by Ivstam[6] from Sweden. Murray[7] made the interesting observation that the increased incidence of cases occurring at the sixth and twelfth week of pregnancy seemed to indicate a greater sensitivity of the inner ear to the virus at these times.

Temporal bones from children and fetuses subjected to maternal rubella during the first three months of pregnancy have been described by Carruthers,[3] Tondury,[8] Schall et al,[9] Kamerbeek[10] and Nager.[11] It is evident from these cases that significant pathological changes in the inner ear have been demonstrated only in the minority of cases exposed to the virus.

Two four and one-half month fetuses reported by Schall et al[9] presented evidence of hemorrhages but no definite abnormality in the appearance of the developing structures in the cochlear duct.

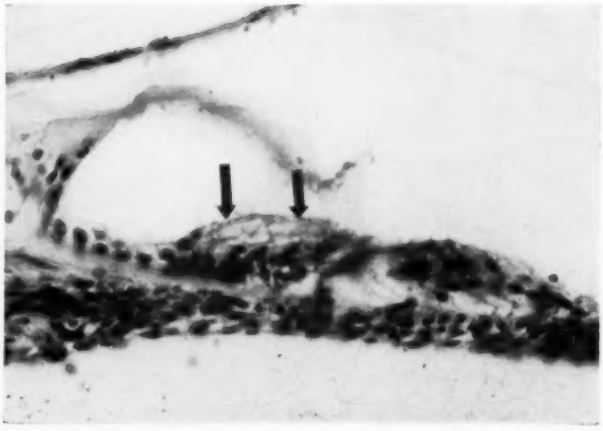

Fig. 2.—Magnification X 550 of the organ of Corti in basal coil shown in Figure 1. Dieters cells and outer and inner hair cells are developed. The tectorial membrane has separated away from Corti's organ. Hensen's cells are inadequately developed. The outer pillar cells are not plainly shown. The group of cells in inner sulcus (arrows) have not yet been absorbed but have separated from the tectorial membrane.

Any relationship of these hemorrhages to the exposure to rubella appears questionable.

The temporal bones from a six and one-half month infant, reported by Carruthers[3] were the first to show definite pathological changes in the cochlear duct.

Of the bones from three children reported by Nager, two cases showed definite malformations. The utricle and semicircular canals were normal in all. The saccule was collapsed in one case. The changes in the cochlear duct consisted of collapse of the duct, a rolled up ensheathed tectorial membrane, anomalies and deficiencies of the stria vascularis and irregular failure of development of the organ of Corti. These findings more or less correspond to the sacculo-cochlear type of deaf mutism, the so-called Scheibe[12] type.

The interpretation made from these histopathologic findings has been that the rubella virus through its action upon the stria vas-

Fig. 3.—Magnification X 550 of the organ of Corti on the middle coil shown in Figure 1. The hair cells, Deiters cells, and pillar cells are moderately well differentiated. The tectorial membrane is still adherent to a group of cells in the inner sulcus. These latter show a lesser degree of absorption than in Figure 2.

cularis affects the endolymph and the epithelium of the ductus cochlearis. This leads to depression and collapse of Reissner's membrane, the changes exhibited by the tectorial membrane and the interference with differentiation of Corti's organ.

This report is made on nine temporal bones from patients exposed to maternal rubella within the first three months of pregnancy. Five of these bones have been obtained by Dr. Douglas G. Carruthers and four are from the University of Chicago collection.

REPORT OF CASES

CASE 1.—These temporal bones were obtained by Dr. Carruthers. They were removed from an eight months old child whose hearing during life was difficult to assess. It is probable that the mother had rubella during pregnancy. The child had the Tetralogy of Fallot and was a mongoloid imbecile.

Histological examination.—The membranous structures showed evidence of having been normally developed but showed marked postmortem degeneration.

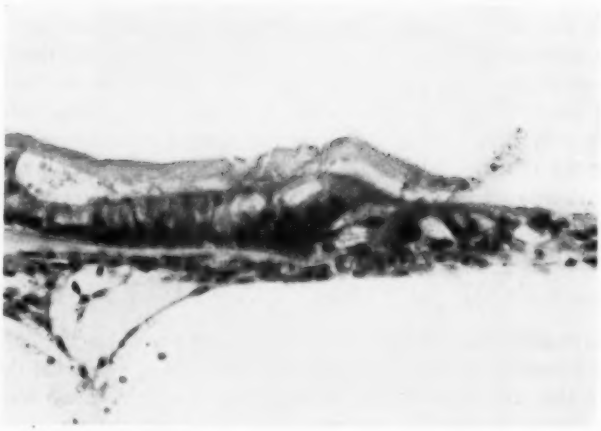

Fig. 4.—Magnification X 550 of the organ of Corti as shown in the apical coil in Figure 1. The cellular structures are less differentiated than in the middle coil. The mass of cells in the inner sulcus shows only beginning absorption. The tectoral membrane has not separated from these cells.

The temporal bones apart from the presence of myeloid metaplasia of the bone marrow were within the limits of normality. The membranous structures of the inner ear showed no definite pathologic changes other than those changes characteristic of post-mortem degeneration.

CASE 2.—(Dr. Carruthers) This infant died at six weeks of age. The mother had an attack of rubella during the seventh week of pregnancy. The child was born with cataracts, a congenital heart lesion and appeared deaf.

Histopathological examination of the temporal bones.—Only one ear was obtained for study.

Middle ear—normal.

Inner Ear.—The membranous structures showed moderate post-mortem degenerative changes. The semicircular canals, utricle and saccule appeared completely normal. Only part of the basal coil of

the cochlea was contained in the specimen. The remainder of the cochlea was missing. In that part of the basal coil contained in the specimen the stria vascularis was normal. The cochlear duct contained a normal quantity of endolymph. The tectorial membrane showed no evidence of pathologic changes. The organ of Corti was not well preserved in the specimen but in some areas pillar cells and Hensen's cells were visible as well as the normal complement of hair cells for the region. Although the condition of the saccule and the cochlear duct of the basal coil with its contained structures showed no pathologic change the possibility of changes in the apical, middle and upper part of the basal coil could not be ruled out.

CASE 3.—S. M. No. 538796. Chicago Lying-In Hospital.

The mother had rubella between August 10 and August 20, 1951. Her last normal menstrual period was in July 1951. As it was thought probable that the fetus would be defective a hysterotomy was done Dec. 4, 1951. The child was previable and lived five minutes. The length was 28.5 cm and it was considered to be between 20 and 22 weeks old.

The post-mortem examination revealed no gross or microscopic abnormality. The temporal bones were prepared and sectioned serially.

Histopathological examination of the ears.

Middle ears.—Normal.

Otic capsules.—Normal.

Inner Ears.—Utricle, saccule and semicular canals were normal. The structures within the cochlear duct showed an incomplete stage of development. The stria vascularis, Reissner's membrane and the quantity of endolymph appeared normal. The hair cells were visible in all coils but less clearly delineated in the apical coil. The pillar cells were fairly well devolped in the basal and middle coils but less clear in the apical coil. Deiter's cells were visible in all coils. Hensen's cell were underdeveloped in all coils.

The mass of cells which lies medial to the region where the pillars develop in the embryo showed various stages of development.

In the basal coil the tectorial membrane had separated off from the inner sulcus cells which had partly regressed thereby forming the space known as the inner sulcus (Fig. 2). In the middle coil

Fig. 5, Case 5.—Mid-modiolar section X 27 showing basal, middle and apical coils. The spiral ganglion and the nerve fibers appear well developed. The stria vascularis is of small extent varying from about one-half of normal in middle coil to almost complete absence in some areas. Reissner's membrane is incompletely preserved (artifacts). The scala media possibly reduced in some areas. The tectorial membrane is abnormal in all coils. The organ of Corti varies from a fairly normal appearance in the middle coil (see Fig. 6) to marked abnormalities of development in the apical coil.

the tectorial membrane had not yet separated from the inner sulcus cells and the latter showed an earlier stage of regression (Fig. 3). In the apical coil (Fig. 4) the inner sulcus cells showed still less regressive change and the tectorial membrane was attached throughout almost its entire extent. The degree of differentiation was therefore greater in the basal coil and progressively less in the middle and apical coils. The two ears were similar. The stage of differentiation of Corti's organ and the tectorial membrane in these ears according to

Patten's[13] modification of Mollendorf's description must be considered within the normal range for a 20-22 week fetus.

CASE 4.—P. B. 5 years of age. No. 327190. University of Chicago Clinics.

The mother had rubella during the sixth week of pregnancy and the child weighed six pounds when born at full term at Chicago Lying-In Hospital. The infant remained in the hospital two and one-half months after delivery as she was found to have bilateral cataracts, a congenital patent ductus arteriosus and was undersized. The teeth developed normally. She fed poorly and was susceptible to infections. She presented a feeding problem and her general development was retarded. She weighed 13 pounds at 18 months. On Feb. 25, 1949 she died at the age of five years. During life the ears were examined on several occasions and the middle ears and the hearing were thought to be within normal limits. The child was subjected to an extensive psychological investigation and it was felt that her intelligence was fairly normal though she did not receive adequate stimulus for mental development at home. It was psychologist's opinion that the child's responses to the tests indicated normal hearing. This case has been reported previously by Lande[14] who also states that the child's hearing was normal. The temporal bones were obtained over twenty-four hours after death and were prepared and sectioned.

Histopathological findings.

Middle ears.—Chronic otitis media and mastoiditis were present on both sides. This condition developed subsequent to the last examination at the University of Chicago Clinics. Bilateral supernumerary muscles recently described by Druss[15] were present.

Inner ears.—Post-mortem degeneration was marked but no significant abnormality of the membranous structures was seen on either side.

CASE 5.—(Case of Dr. Carruthers). These are the temporal bones of a child five years of age who died of acute encephalitis. It is known that his mother had rubella during early pregnancy but the exact time at which it occurred is uncertain.

Examination showed a threshold hearing for pure tones averaging 80 decibels in the left ear and almost total absence of hearing

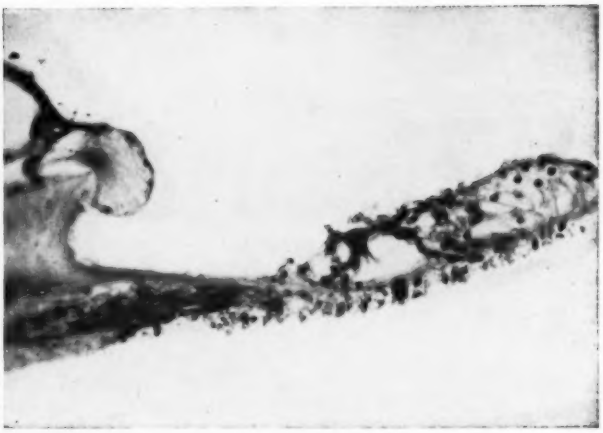

Fig. 6, Case 5.—Magnification X 450 of the organ of Corti and tectorial membrane of the membrane coil shown in Figure 5. Hensen's cells, Deiter's cells and the inner cell appear normal. The outer pillar cell appears defective. Outer hair cells and inner hair cells show degenerative changes (post-mortem?) but the nuclei are present. The tectorial membrane is rolled up against the limbus and is ensheathed by a thin cellular membrane.

in the right ear. The temporal bones were removed eighteen hours after death.

Histopathological findings.—Left ear.

Middle ear.—Normal.

Inner ear.—The bony labyrinthine capsule appeared normal. The membranous structures showed a moderate degree of post-mortem degenerative changes. The utricle and semicircular canals showed no abnormality. Reissner's membrane appeared to be partially collapsed but not adherent to Corti's organ. The stria vascularis varied considerably in different coils, in some being almost absent and in others about half of its normal extent (Fig. 5). Corti's organ showed variations in its appearance. The general contour of the organ was fairly well preserved. The cells of Hensen, Claudius and Deiters were about normal in appearance. The pillar cells appeared normal in the basal and middle coils but in the apical coil showed evidence

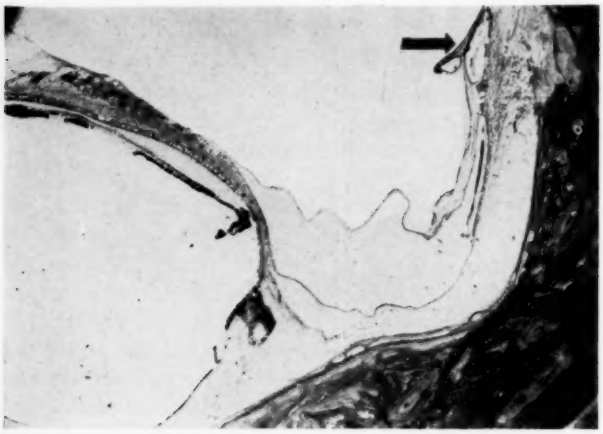

Fig. 7, Case 5.—Magnification X 48. The utricular macula appears normal except for post-mortem degeneration. The saccule shows the reinforced area of Perlman (arrow) to be thickened and the lateral wall of the saccule for some distance beyond this to be greatly thickened or hypertrophic with a broad adhesion to the central portion of the macula. The macula has degenerated at the point of adhesion but shows an otolithic membrane in other areas.

of incomplete development. The hair cells were poorly defined but the changes, particularly in the basal and middle coils could mostly be explained by the degree of post-mortem degeneration (Fig. 6). In the apical coil there were definite changes suggestive of failure of development.

Notable changes were evident in the tectorial membrane. In most areas it appeared rolled up against the limbus partly in contact with Reissner's membrane and encased in a sheath of flattened cells (Fig. 4). In the apical coil the tectorial membrane extended down into the inner sulcus. In no area was it found in the normal position over Corti's organ. The cells of the spiral ganglion and the nerve fibers appeared normal in number and showed no evidence of degeneration.

There was some recent bleeding into the internal auditory meatus.

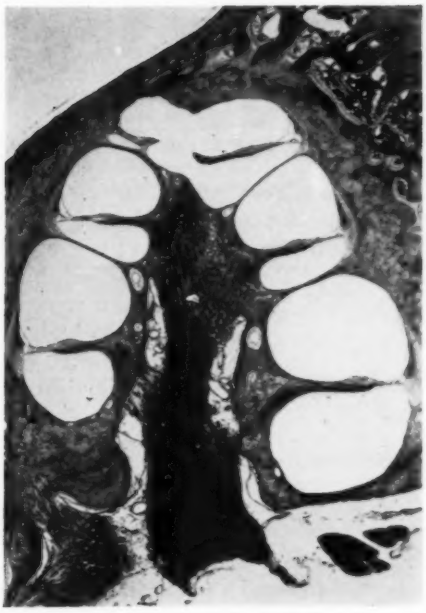

Fig. 8.—Cochlea of congenitally deaf Dalmatian pup. Mid-modiolar sections X 27. The spiral ganglion and nerve fibres appear normally developed. Reissner's membrane is collapsed and adherent to the stria and the organ of Corti in most areas. The stria vascularis is devoid of blood vessels. The organ of Corti and tectorial membrane show lack of development.

Striking changes were seen in the saccule. The lateral wall, including the reinforced area described by Perlman,[16] was greatly thickened or hypertrophic and adherent to the macula in irregular areas. The remaining medial part of the wall was of normal thickness and the lumen in that region was of normal width. The macula was degenerated in the adherent areas but in intervening spaces showed areas with more normal development (Fig. 7).

The changes in the saccule may be summarized as consisting of hypertrophy and adhesions of the saccular wall to the macula in irregular areas with resulting gross defects in the macula.

The right ear showed essentially the same type of abnormalities as the left. The degree of differentiation of the organ of Corti appeared to be less advanced. This may have explained the profound loss of hearing on the right side as compared to a severe loss on the left.

SUMMARY OF HISTOPATHOLOGICAL FINDINGS

In three out of four cases exposed to maternal rubella in the early months of fetal life the inner ear showed no significant pathological change. The fifth case showed no pathological change in the semicircular canals, otolithic organs or basal coil, but the upper part of the basal coil, the middle and apical coils were not available for examination.

Three of the five cases showed other stigmata commonly found after maternal rubella.

One case showed no malformations. One case showed bilateral inner ear changes.

In the latter case which had known deafness the utricles and semicircular canals were normal. The pathologic changes were limited to the saccules and structures within the cochlear ducts, a typical sacculo-cochlear type of malformation. The saccules showed extensive changes on both sides.

The scala media showed only a mild degree of depression of Reissner's membrane, but no adhesions except to the rolled up tectorial membrane at the limbus.

The stria vascularis varied considerably in different coils, in some being almost absent and in others about half its normal extent.

Corti's organ showed development to be about normal in the basal and middle coils on one side, but deficient in the apical coils, whereas the defective development was more extensive on the opposite side.

The tectorial membrane was abnormal in all areas and in none of the sections did it appear to have been attached in the normal position over Corti's organ. It was covered by a sheath of flattened cells.

Fig. 9.—Magnification X 165 of cochlear duct of the basal coil shown in Figure 6. This shows the absence of vessels in the stria and the adherent Reissner's membrane. The tectorial membrane is depressed into the inner sulcus and covered by a cellular sheath. There is a lack of development of the cellular components of the organ of Corti.

DISCUSSION

The present report includes the inner ear findings in both ears of four cases whose mothers had rubella in the early months of pregnancy. The semicircular canals and vestibular structures of one ear of a fifth case are also included. Although other congenital malformations were present in three of these five cases the inner ears showed pathological changes in only one. This case exemplifies the sacculo-cochlear type of malformation which has been referred to as the Scheibe type of congenital deafness. The impression has been [12, 17, 18, 19] that the changes found within the cochlear duct in this type have been secondary to changes in the stria vascularis. Such a sequence might be suggested also by the findings in the ears of hereditarily deaf Dalmation dogs.

The ears of two of these dogs,* known to be deaf, have been sectioned for study. The animals were six months of age but whether

*Obtained through courtesy of Dr. William D. Neff, Associate Professor, Laboratory of Physiological Psychology, University of Chicago.

any hearing was present after birth was not definite. In these ears the stria vascularis was avascular and the cochlear duct and saccule collapsed, indicating a lack or absence of endolymph. The tectorial membrane and Corti's organ were abnormal throughout showing evidence of arrest of development in an earlier stage than in the rubella bones (Figs. 8, 9 and 10). In some areas the tectorial membrane was rolled up and enclosed by a cellular sheath, similar to that seen in the rubella bones. This corresponds to findings reported by Lurie.[19] In this type of malformation the absence of a vascular stria and endolymphatic fluid appeared to be of fundamental importance.

In this pair of ears damaged by maternal rubella, the limitation of the stria vascularis to less than half of normal was probably still compatible with maintenance of normal endolymph and normal function of structures within the cochlear duct. According to Crowe, Guild and Polvogt,[21] a considerable degree of atrophy of the stria vascularis must be present before any effect upon hearing can be demonstrated. Moreover, extensive atrophy of the stria vascularis has been shown to be compatible with good hearing in the case of Ménière's disease reported by Day and Lindsay.[22] The fact that the extent of the stria was greatly limited may however be interpreted in this case as an indication of the action of the rubella virus. During the period of such activity a change in the endolymph probably occurred with transmission of the inflammatory effect to the structures developing within the cochlear duct and saccule. In this case the interference with function was explainable by two factors; the incomplete development of the organ of Corti in some areas and the pathologic state of the tectorial membrane. It is probable that, even where the organ of Corti appeared otherwise normal, it would have been incapable of function since the tectorial membrane was not in its normal position but rolled up in a rounded mass encased in a cellular sheath. The malformation of the tectorial membrane and Corti's organ may therefore have been the direct cause of the deafness.

It is significant that the peripheral cochlear neuron did not appear to show any definite abnormalities. Apparently the lack of development of the pillar cells and hair cells in both the ears affected by rubella and in hereditary deafness in dogs did not interfere with the development of the peripheral cochlear neuron. The situation is different in the case of experimental head blows in cats in which acoustic injury sufficient to cause degeneration of the pillars was followed rapidly by degeneration of the neuron.[23]

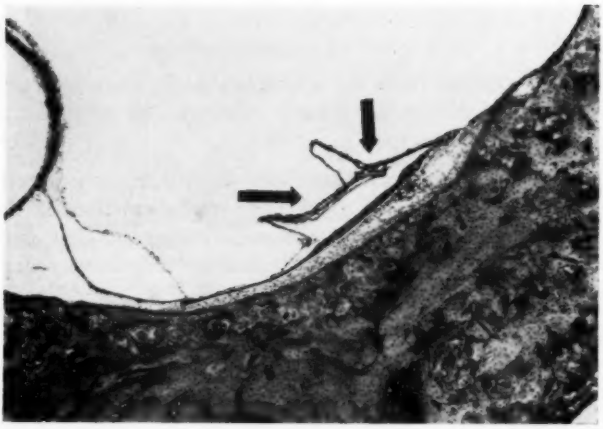

Fig. 10.—Deaf Dalmatian pup, magnification X 70. Section through the saccule. The lateral wall shows hypertrophy and irregularities. The walls of the saccule are collapsed through all sections.

A similar state of the tectorial membrane has been observed in cats deafened experimentally.[24] The roiled-up tectorial membrane ensheathed by a thin layer of cells was seen in the area where the organ of Corti was also degenerated and hearing absent. This condition of the tectorial membrane has not been confined to experimental or inflammatory states since it was also seen in the deafened dogs in which the condition was hereditary. Clinical evidence indicates that when the differentiation has progressed to a certain degree the stria vascularis is then resistant to damage by the virus. The precise period when the developing ear is exposed as well as the virulence of the particular strain of virus are probably both determining factors.

There appears to be no evidence to indicate that these lesions can be attributed to post-hydropic degeneration as postulated by Wittmaak or that a hydrops has ever existed in these ears. In certain experimental injuries in the ears of monkeys and rabbits we have shown that relatively mild degrees of inflammatory reaction in the perilymphatic fluids may produce extensive degeneration of the

primary cochlear neuron and the structures in the cochlear duct without any significant degree of hydrops. In contrast an extensive hydrops is seen in Ménière's disease without any histological evidence of degeneration of the primary cochlear neuron.

It would appear from the evidence that in maternal rubella the virus reaches the developing sensory structures by way of the blood vessels and the endolymph.

The saccular abnormalities were a striking characteristic of this case. The presence of thickening and distortion of the walls with intermittent adhesions to the macula suggests that during the exposure to the virus collapse of the saccule may have occurred.

The limitation of the malformations to the cochlear duct and saccule is not readily explained. The question arises as to whether the endolymph in the utricle and semicircular canals may be effectively isolated from that of the saccule and cochlea by the utriculo-endolymphatic valve. Presumably the virus infection is blood borne. The stria vascularis is the most vascular area in the membranous inner ear and therefore the endolymph of the cochlea and saccule might be subjected to a larger concentration of the virus irritant thereby explaining a predilection for damage to the saccule and cochlea.

SUMMARY

Both inner ears from four cases exposed to maternal rubella in the early months of pregnancy have been examined microscopically. The semicircular canals and vestibular structures of one ear of a fifth case have also been studied. Three of these cases had other abnormalities commonly found following maternal rubella. One case was known to have severe bilateral deafness and the ears showed a bilateral sacculo-cochlear type of pathology.

The mid-term fetus showed a lack of differentiation of the organ of Corti and the tectorial membrane which in the light of existing information, may have been within normal limits.

The abnormalities in the saccule consisted of thickening and distortion of the wall and adhesions to the macula with corresponding areas of macular degeneration.

In the cochlear duct the malformations of the tectorial membrane and Corti's organ were considered to be the explanation for the loss of function.

The reduction in the extent of the stria vascularis has been interpreted as an indication of the direct effect of the rubella virus which in turn permitted a greater concentration of the virus irritant in the endolymph, resulting in injury to the developing structures within the cochlear duct and saccule.

950 E. 59TH ST.

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Abstracts of Current Articles

EAR

Vertigo: A Therapeutic Approach Based Upon Its Physiopathological Aspect.

Welt, Bernard: *A. M. A. Archives of Otolaryngology* 58:273-300 (Sept.) 1953.

The etiologic or pathogenic basis for dizziness usually furnishes the background for the therapeutic approach. However, Welt applied the knowledge gained through Revici's research on pathologic tissues and felt that relatively independent of the etiologic and pathologic factors involved, the metabolism of the abnormal tissues, involved in the production of this symptom, corresponded to two general patterns—one producing local acidosis, the other local alkalosis. The author's treatment of 44 patients with acute vertigo was based on this assumption, treating those with alkaline symptoms with acid preparations and vice versa. Welt has written a lengthy treatise explaining in detail the reasoning back of his conclusions. He claimed to have controlled the symptom of dizziness in 80 per cent of his series through this method but it is difficult for this reviewer to accept the premises of Revici, upon which all of this work is based.

HILDING.

LARYNX

Congenital Laryngeal Stridor.

Kelemen, George: *A. M. A. Archives of Otolaryngology* 58:245-268 (Sept.) 1953.

This excellent article does not lend itself readily to abstracting in brief form. The author's outline of the contents sets forth the chief points covered and includes general considerations of the subject, materials and methods of his study on eight laryngeal specimens (four from infants with laryngeal stridor and four from infants without such symptoms), case histories, comments on anatomy, pre and posnatal development, comparative anatomy, autopsy findings, microscopic anatomy, birth trauma, character of vocal performance, comparative phonetics and therapy. The generous number of references to the literature and 30 photomicrographs attest to the thorough

preparation of this article, which will yield rich dividends to the reader who will devote his attention to it.

HILDING.

ESOPHAGUS

Cortisone and Acute Lye Corrosion of the Esophagus.

Smith, Vernon M., Crompton, James R., and Palmer, Eddy D.: A. M. A. Archives of Otolaryngology 58:235-244 (Sept.) 1953.

The authors point out the division of opinion as to which of the present accepted courses of treatment for this condition should be followed but state that esophageal stricture regularly complicates severe lye corrosion of the esophagus unless a long program of mechanical dilatation is undertaken. Histologically, the stricture of the esophagus following lye burn, is known to result from fibroplasia subsequent to tissue injury. Collagen fibers produced in the presence of fibroblasts contract to form the stricture. The fibroblastic invasion of an injured area begins in a period as brief as three or four days following injury. Prevention of fibroplasia might be expected to inhibit stricture formation by inhibiting collagen deposition. Cortisone has been shown to inhibit the fibroplasia of inflammation. One report from the literature cited the instance of a 17 months old boy in whom cortisone administration was begun on the first day of illness (after drinking lye); he was treated with cortisone and Terramycin® for 12 days and no stricture developed during the 13 month period of observation.

An 18 year old youth, who had an acute lye burn of the esophagus, and was treated in the Gastrointestinal Section of Walter Reed Army Hospital, is the subject of a report by the authors in which day by day progress is described. Antibiotics were started on the second day and cortisone therapy on the 10th day (with KCl enteric coated tablets taken concurrently with the cortisone). Stricture developed in spite of this treatment and cortisone therapy was discontinued on the 19th day and active dilatation begun. The reviewer might pose the question at this point, if the cortisone had prevented stricture formation, would healing of the esophagus have taken place?

This failure of cortisone to prevent stricture formation is believed by the authors to perhaps be due to delayed administration and they point to certain histologic studies and work on animals in support of this theory. The lapsed time before institution of therapy was sufficient to permit of early fibroplasia and fibrosis. For great-

est retardation of fibrosis, cortisone should be given before fibroplastic invasion of the injured area begins. The complicating problems of cortisone administration in cases of lye burn are described with the caution that one must evaluate each situation and decide whether cortisone will aggravate a manifest suicidal tendency. One must be alert to the tendency of cortisone to enhance the spread of infection and to suppress the clinical signs thereof. A tentative program of management to be tried in the next case of lye burn of the esophagus admitted to their hospital is outlined (16 points) including hospitalization, close supervision, frequent roentgenographic study and liberal use of antibiotics in addition to the administration of cortisone beginning on the first day and accompanied by KCl enteric coated tablets.

HILDING.

MISCELLANEOUS

Penicillin as Thromboplastic Agent.

Volk, Benjamin M., and Mukerji, S.: A. M. A. Archives of Otolaryngology 58: 269-272 (Sept.) 1953.

This study was instituted because of the controversial reports on the effects of parenterally administered penicillin on the clotting mechanism of blood. One hundred patients, largely under 12 years of age, undergoing routine tonsillectomy and adenoidectomy, were equally divided into two groups of 50 each, one group receiving a minimum total of 1,200,000 I.U. of Penicillin G during their hospitalization and the other (control) group not receiving any penicillin. The patients were operated upon the day after admission and discharged the day following surgery. On admission and discharge all patients had the following laboratory work done: complete blood counts, hemoglobin, bleeding time, clotting time, clot retraction time, capillary fragility and prothrombin time. The technique of the blood work was standardized. Vitamin K was not prescribed and the use of aspirin was not restricted. Strict watch was kept on both groups for postoperative bleeding. Only two patients had postoperative hemorrhage—one in the penicillin group, occurring seven days postoperatively, and one in the control group, occurring eight hours postoperatively. As a result of this study, no significant alteration in the previously mentioned blood tests was found to have occurred, leading to the conclusion that penicillin used parenterally has no significant thromboplastic activity.

HILDING.

Books Received

Essays on the Applied Physiology of the Nose.

By Arthur W. Proetz, A.B., M.D., Sc.D., Professor of Clinical Otolaryngology in the Washington University School of Medicine. xxiv+452 pp. Octavo, cloth, illustrated. Annals Publishing Co., St. Louis. (Price $8.00)

This second edition of a well-known work follows the first by some twelve years and three printings. While retaining the original format, the material has been completely revised and brought up to date; 57 pages and 39 new illustrations have been added.

From the beginning this has been generally accepted as the standard text on the physiology of the nose, and as such has been widely quoted in contemporary books on laryngology and rhinology and in current literature. Based originally on a course of twenty lectures and the author's own numerous investigations, it retains the characteristics of a text-book and a source of references for students and investigators; it is amply documented and well indexed.

However, each chapter is in the style of an essay, making continuous reading more enjoyable and giving the author some latitude in expressing his own opinions and conclusions more freely than a strict text-book treatment would permit.

Dysarthric Speech

By Emil Froeschels, M.D., President International Society for Logopedics and Phoniatrics, President New York Society for Speech and Voice Therapy, Inc., Physician in charge of the Speech-Voice Clinic, Beth David Hospital, New York City. Pp. 172, Crown 8 vo., illustrated, Expression Company, Magnolia, Mass., 1952.

Allergic Problems in Otorhinolaryngology (Problemi di Allergologia in Otorinolaringologia).

Volume 64, Supplement XIII of the Archivo Italiano di Otologia Rinologia e Laringologia. (In Italian. Summaries in English and French), Royal 8 vo, paper, Pp. 257, 1953.

Allergic problems in otorhinolaryngology discussed by fourteen authors from the Otorhinolaryngologic Clinic of the University of Milan.

Cancer of the Larynx and the Hypopharynx. (Il cancro della Laringe e dell' Ipofaringe).

Volume 64, Supplement XIV of the Archivio Italiano di Otologia Rinologia e Laringologia. (In Italian. Summaries in English and French), Royal 8 vo, paper, Pp. 257, 1953.

Clinical and pathological problems discussed by eleven authors from the Otorhinolaryngological Clinic of the University of Milan.

A Guide to Help the Severely Hard of Hearing Child.

By Helen Hulick Beebe, Formerly Teacher in Oral Schools for the Deaf. 8 vo., Pp. 47, S. Karger Ltd., Basle, Switzerland, 1953. (Price, 6 Swiss francs).

Keep Your Voice Healthy.

By Friedrich S. Brodnitz, M.D. Pp. 234, illustrated. New York, N. Y., Harper and Brothers, 1953. (Price $3.50)

Notices

AMERICAN LARYNGOLOGICAL ASSOCIATION

CASSELBERRY PRIZE

A sufficient sum having accrued from the Casselberry Fund for encouraging advancement in the art and science of Laryngology and Rhinology, this sum is now available, in part or as a whole, for a prize award. Theses must be in the hands of the Secretary, Dr. Harry P. Schenck, 326 South 19th Street, Philadelphia, Pa., before March 1, 1954.

UNIVERSITY OF PENNSYLVANIA

Announcement is made of the personal fundamental course in Bronchology, Esophagology, Gastroscopy and Laryngeal Surgery at the Graduate School of Medicine, University of Pennsylvania. The course begins September eighth and continues through September nineteenth.

Courses are scheduled usually in January, June and September avoiding conflict with the meeting dates of the National Medical Societies.

Application may be made to Dr. Aims C. McGuinness, Dean, or to Dr. Gabriel Tucker, Chairman of the Department of Bronchology, Esophagology, and Laryngeal Surgery.

NINETEENTH INTERNATIONAL CONGRESS OF OTO-NEURO-OPHTHALMOLOGY

The Nineteenth International Congress of Oto-Neuro-Ophthalmology will be held on the occasion of the commemoration of the foundation of São Paulo, from June 11th to 17th, 1954 in the city of São Paulo (Brazil).

Inquiries should be addressed to:

Clínica Oftalmológica
Hospital das Clínicas
São Paulo
Brazil

PAN-AMERICAN CONGRESS

Fourth Pan-American Congress of Oto-rhino-laryngology and Broncho-esophagology, Mexico City, February 28 to March 4, 1954. Dr. Ricardo Tapia Acuna, President, Dr. Maximo Garcia Castaneda, Secretary.

FLORIDA MIDWINTER SEMINAR

The eighth annual University of Florida Midwinter Seminar in Ophthalmology and Otolaryngology will be held at the Sans Souci Hotel in Miami Beach the week of January 18, 1954. The lectures on Ophthalmology will be presented on January 18, 19, and 20, and those on Otolaryngology on January 21, 22 and 23. A midweek feature will be the Midwinter Convention of the Florida Society of Ophthalmology and Otolaryngology on Wednesday afternoon, January 20, to which all registrants are invited. The registrants and their wives may also attend the informal banquet at 8 p. m. on Wednesday. The Seminar schedule permits ample time for recreation.

The Seminar lecturers on Ophthalmology this year are: Dr. W. B. Anderson, Durham, N. C.; Dr. W. P. Beetham, Boston; Dr. W. C. Owens, Baltimore; Dr. A. B. Reese and Dr. M. C. Wheeler, both of New York City; on Otolaryngology: Dr. E. N. Broyles, Baltimore; Dr. H. P. House, Los Angeles; Dr. W. J. McNally, Montreal; Dr. Dorothy Wolff and Dr. D. Woodman, New York City.

Please address inquiries to H. Marshall Taylor, M. D., Jacksonville or Walter T. Hotchkiss, M.D., Miami Beach.

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President: Dr. Francis LeJeune, Prytania and Olive Sts., New Orleans, La.
Secretary: Dr. C. Stewart Nash, 708 Medical Arts Bldg., Rochester, N. Y.
Meeting: Boston, Mass., May 25-27, 1954.

American Medical Association, Section on Laryngology, Otology and Rhinology

Chairman: Dr. Carl H. McCaskey, 20 N. Meridian St., Indianapolis, Ind.
Secretary: Dr. Sam H. Sanders, 1089 Madison Ave., Memphis 3, Tenn.

American Otological Society

President: Dr. Frederick T. Hill, Professional Bldg., Waterville, Maine.
Secretary-Treasurer: Dr. John R. Lindsay, 950 East 59th St., Chicago 37, Ill.
Meeting: Boston, Mass., May 23 and 24, 1954.

The American Society of Ophthalmologic and Otolaryngologic Allergy

President: Kenneth L. Craft, M.D., 23 East Ohio Street, Indianapolis, Indiana.
President-Elect: Albert D. Ruedemann, M.D., 1633 David Whitney Building, Detroit 26, Michigan.
Secretary-Treasurer: Michael H. Barone, M.D., 468 Delaware Avenue, Buffalo 2, New York.

International Bronchoesophagological Society

President: Dr. André Soulas, Paris, France
Secretary: Dr. Chevalier L. Jackson, 1901 Walnut St., Philadelphia 3, Pa.
Meeting: Third International Congress of Bronchoesophagology, Fall of 1954, Lisbon, Portugal.

Pacific Coast Oto-Ophthalmological Society

President: Leland G. Hunnicutt, M.D., 98 N. Madison Ave., Pasadena 1, Calif.
Secretary-Treasurer: John F. Tolan, M.D., 3419 47th Ave., N.E., Seattle 5, Wash.
Meeting: Honolulu, 1954.

Pan-American Association of Oto-Rhino-Laryngology and Broncho-Esophagology

President: Dr. Justo M. Alonso, Montevideo.
Secretary: Dr. Chevalier L. Jackson, 1901 Walnut St., Philadelphia 3, Pa., U.S.A.
Meeting: Fourth Congress of Oto-rhino-laryngology and Broncho-esophagology.
President: Dr. Ricardo Tapia Acuña, Mexico City.
General Secretary: Dr. Maximo García Castaneda.
Time and Place: February 28th to March 4th, 1954, Mexico City.

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